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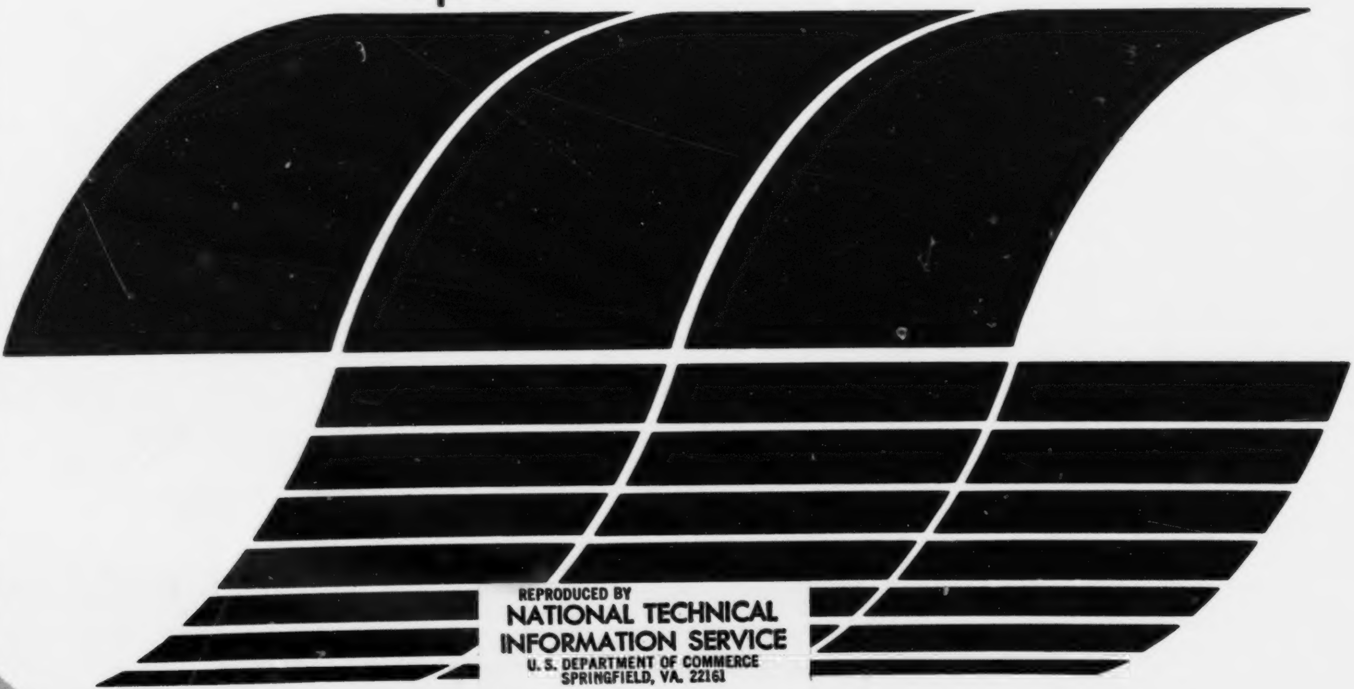
Coal Surface Mining and Power Production in the Face of Environmental Protection Requirements

Interagency Energy/Environment R&D Program Report



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PROCEEDINGS
# of the
Second U.S.-Polish Symposium

COAL SURFACE MINING AND POWER PRODUCTION IN THE FACE OF ENVIRONMENTAL PROTECTION REQUIREMENTS

September 26-28, 1979

Castle Ksiaz, Poland

Symposium Director

Dr. Jacek Libicki
Central Research and Design Institute for Openpit Mining
POLTEGOR
Wroclaw, Poland

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

When energy and material resources are extracted, processed, converted and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

An essential part in the progress of environmental research is the continuing seven-year cooperative venture between the U. S. Environmental Protection Agency and the Polish organization for open-pit mining (Poltegor). Of the ten studies conducted by Poltegor and sponsored by the EPA, at a value of more than 3 million U. S. dollars, five are already completed and final reports have been edited and distributed in both countries. The large demand for these reports demonstrates the interest in this work. The completed projects have clarified the problem of ground water pollution by disposal of the coal refuse and ashes, demonstrated improved methods of reclamation of toxic spoils and alkaline ash piles, shown methods of mine water purification, and developed methods of drying tailings and thickening sludge.

A significant part of the cooperative EPA/Poland efforts has been the direct contacts between the specialists from each country. An outgrowth of this exchange of experiences has been joint conferences and symposia. This 1979 Symposium in Poland is the second--the first one took place in Denver, Colorado, in 1975. This Poland Symposium further develops the understanding of mutual problems and achievements for the protection of the environment in mining and power production operations.

The success of both these meetings allows us to express a hope that these meetings and the whole cooperation will continue to the benefit of both our countries.

This report is a compilation of the research papers presented at the Poland Symposium on "Coal Surface Mining and Power Production in the Face of Environmental Protection Requirements." These papers will be of interest to individuals or organizations concerned with environmental aspects of coal and lignite mining and their relationship with power generation. Further information can be obtained from the Resource Extraction and Handling Division, IERL-Cincinnati.

Dr. Wladyslaw Witek
President
Lignite Mines and Power
Plants Corporation
Poland

Roger Williams
Deputy Regional Administrator
USEPA
Denver, Colorado

David G. Stephan
Director
Industrial Environmental
Research Laboratory
USEPA, Cincinnati, Ohio

ABSTRACT

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OVERVIEW OF THE UNITED STATES ENVIRONMENTAL RESEARCH PROGRAM RELATED TO COAL EXTRACTION CONVERSION THROUGH THE YEAR 2000

by

Ronald D. Hill x/

ENERGY SUPPLY

The United States leads the World in per capita use of energy. President Carter's April 1977 National Energy Plan projected the energy needs to be 123.5×10^{15} BTU by 2000 up from the 1975 level of 73.2×10^{15} BTU. In Table 1, the energy sources for 1975 and those projected for 1985 and 2000 are presented. As noted oil will continue to be the greatest source through 1985. However, the National Energy Plan calls for coal to be the major source by 2000.

Table 1

PROJECTED ENERGY SUPPLY PATTERN (1975 - 2000)
(10^{15} BTU)

Energy source	1975	1985 NEP	2000 NEP
Coal	15.3	28.2	44.9
Oil	20.7	22.1	20.8
Oil Imports	12.8	13.3	13.0
Gas	18.6	17.6	15.4
Gas Imports	1.0	1.8	1.1
Nuclear	1.8	7.6	18.7
Solar	0	0.3	1.8
Geothermal	0	0.3	2.7
Hydropower	3.0	3.1	3.6
National Total	73.2	94.3	123.5

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x/ Ronald D. Hill, Director - Resource Extraction and Handling Division, Industrial Environmental Research Laboratory - Cincinnati U.S. Environmental Protection Agency Cincinnati, Ohio 45268.

Table 2

ANNUAL PRODUCTION OF COAL (1975 - 2000)
(10^{15} BTU)

	NEP
Underground Mines	
1975	7.3
1985	9.8
2000	15.7
Surface Mines	
1975	7.9
1985	18.3
2000	29.2
Total	
1975	15.2
1985	28.1
2000	44.9

NEP - Projection based on President's National Energy Plan, April 29, 1977.

As noted in Table 2, the largest increases in coal will come from surface mines. The 1975 coal productions in the United States was 50 million tons, of which slightly over half came from surface mines.

COAL DEPOSITS

Figure 1 presents the coal deposits of the United States and Table 3 important data on each coal region. The Appalachian and Eastern Interior regions have bituminous coal of high BTU values and also often high sulfur contents. The coal seams are usually thin. The Western Region is predominantly subbituminous and lignite coals. The BTU content and sulfur content are low and often the coal seams are thick.

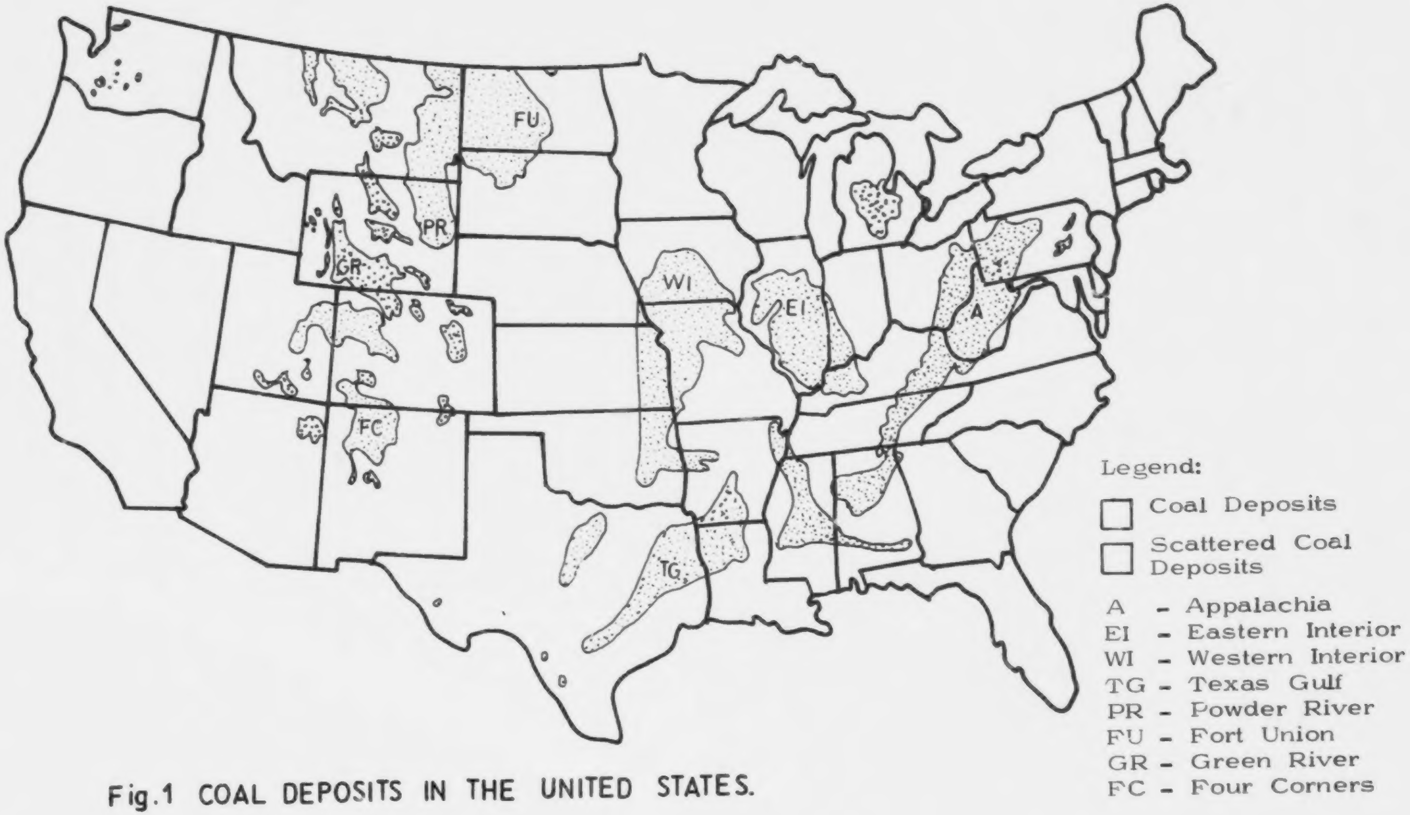
FU
PR
GR
FC
WI
EI
A
TG
Legend:
☐ Coal Deposits
☐ Scattered Coal Deposits
A - Appalachia
EI - Eastern Interior
WI - Western Interior
TG - Texas Gulf
PR - Powder River
FU - Fort Union
GR - Green River
FC - Four Corners

Fig.1 COAL DEPOSITS IN THE UNITED STATES.

Table 3

COAL REGION CHARACTERISTICS

Coal Region	Recoverable Reserves (billions tons)	Meets EPA[x/] SO_2 Standards	Can be Physically Cleanable to Meet EPA SO_2 Standards	Average Seam Thickness Feet	Acres Disturbed per million tons of Coal Surface Mined
Western	141	70	94-98	-	-
Powder River	-	-	-	26	22
Fort Union	-	-	-	10	57
Green River	-	-	-	8	71
Four Corners	-	-	-	8	71
Western Midwest	11	3	6	5.5	104
Eastern Interior	51	1	2-4%	5.5	104
Appalachia	-	-	-	6.0	95
Northern	36	4	12-31	-	-
Southern	20	35	50-63	-	-
Total	260	14	24-32	-	-

[x/] Standard - 1.2 lb SO_2 per million BTU.

EPA SULFATE TECHNOLOGY RESEARCH AND DEVELOPMENT

EPA has been instrumental in developing, testing, and assessing alternative sulfur control technologies since the early 1960's. Their research has emphasized the demonstration of technical feasibility to ensure economic acceptance by industry.

There are three basic points at which sulfur pollutants can be removed from the coal power cycle-before combustion (physical or chemical cleaning, synthetic fuels), during combustion (fluidized bed combustion), or from the exhaust gases after combustion (flue gas desulfurization). EPA has had a major national research role in all of these areas.

COAL CLEANING

Less than 15 % of the coal mined in the United States today can meet federal standards governing sulfur oxide emissions from new sources. At EPA, work has continued on the development of several sulfur removal options for coal. This work includes testing system feasibilities, determining cost figures for industry application, and providing information that can be used by regulating authorities for assessing practical and optimum emission control strategies.

The coal cleaning process is complicated by the very nature of coal. Coal is not homogenous. Different seams, or different locations within the same seam or mine, can yield vastly different coal samples in terms of heat value, sulfur, ash and water content. Sulfur itself, within the coals, takes two forms: pyritic sulfur is separable from the coal by physical means (e.g., crushing), organic sulfur is tightly bound to the coal and is difficult to remove.

Part of the work of EPA is determining the physical cleanability of various U.S. coals. Under this program, the ultimate cleanability of most major deposits has been determined. This work, which has been performed in conjunction with the U.S. Bureau of Mines, has tested more than 450 samples of coal representing more than 70 % of the coal used for U.S. utilities. From these tests EPA and the Bureau of Mines have determined the level of sulfur reduction that can be achieved by physical cleaning as the degree of energy loss associated with the cleaning process. There are two basic methods of removing this sulfur: physical coal cleaning and chemical coal cleaning.

CHEMICAL COAL CLEANING

Chemical coal cleaning requires run-of-mine coal to be ground to fine granules, after which it is reacted with chemical agents at elevated temperatures and/or pressures to remove impurities and sulfur compounds. Again, this 'cleaning' is performed before combustion.

Several chemical coal cleaning processes are under development. The Meyers Process is the most advanced of these and is currently being evaluated in a 1/3-ton-per-hour pilot plant in Capistrano, California. This process has the potential to remove more than 95 % of the pyritic sulfur.

At least eight other processes are in various stages of development in benchscale studies. These processes include microwave desulfurization, hydrotreatment and hydrothermal processes, the latter processes claiming 90 % removal of pyritic sulfur and 40 % removal of organic sulfur. While most of the chemical coal cleaning processes being examined by EPA are capable of removing both organic and pyritic sulfur, the effectiveness of any given process depends on the chemical makeup of the mined coal. Under accelerated development, several chemical processes could be ready for commercial demonstration in 3 to 5 years.

SCRUBBERS

The most promising sulfur-control technology to date has been a flue gas desulfurization (FGD) 'scrubbing' technique for which nearly $ 4 billion has been committed by industry. The combined electrical power output represented by this investment is 40,000 megawatts or 10 % of this nation's generating capacity.

RESEARCH INTO FGD

RGD systems can either be throwaway systems which require that the by-product sludge be discarded, or regenerable systems that produce a by-product with some use. The FGD systems now in the greatest use are the lime and limestone sludge-producing systems. In these systems, the sludge comes from a lime or limestone that precipitates $S0_2$ into a calcium sulfate or calcium sulfite salt.

The year 1977 saw the initiation of a major test of what may become the next generation scrubber system, the double alkali scrubbing process. Earlier pilot plant tests using the double alkali scrubbing process have indicated improved reliability, significantly improved energy efficiency, and potentially lower capital and operating costs than other scrubbing systems.

FLUID BED SYSTEMS

The third method of reducing SO_2 emissions from fossil fuel combustion is fluidized bed combustion (FBC). This technology involves the combustion of pulverized coal or 'dirty' residual oil in a bed of limestone that has been fluidized (held in suspension by the controlled injection of air through the bottom of the bed). During combustion, the SO_2 released reacts with the limestone to form a dry solid waste along with the coal ash. This waste thus removes much of the pollution before it enters the exhaust gas. High heat transfers, low sulfur and nitrogen oxide emissions, and responsiveness to varying loads and composition are just a few of the FBC's advantages. EPA anticipates relatively early commercial availability of this process. In 1977, EPA work on FBC has continued on technical applications, emissions control, environmental impact, projected cost comparisons with other sulfur control technologies, and applications to electric utility and large industrial boilers. The process offers the potential of solving the problem of clean energy for medium-scale operations, but it is currently not commercially available for the large boilers required by electric power plants and heavy industry. Although fluidized bed combustion is not a cleaning process per se, it serves a similar environmental function and is, therefore, of interest to ORD.

Other promising technologies involve the creation of low-sulfur synthetic liquid or gaseous fuels from coal. These technologies, under development by the Department of Energy (DOE), are being reviewed in a cooperative ORD/DOE environmental monitoring program. Such synthetic fuels technologies, however, are not expected to make a significant contribution to the nation's energy supply for several years.

These control technologies are essential for establishing alternative strategies to meet the sulfate hazards of the future. The focus of the control technology research in both 1977 and future years is to make technical options available to coal users as well as control options for regulation. The research is paying close attention to costs of control, to a phasing of controls into new plants, and to the retrofit problems of existing plants.

COMBINING TECHNOLOGIES

Additional studies performed by ORD indicate that, in many instances, a combination of two or more of coal cleaning and sulfur removal methods can be the most cost effective and efficient method of meeting a specified $S0_2$ emission standard. Among the determining factors are the emission standards to be met, the location of the plant, the type and makeup of coal, the available water and other necessary resources, the location of end users, and the technical feasibility and costs of the methods.

Continued R&D on all feasible sulfur removal options is essential as the need for energy increases, and as more and better use must be made of the U.S. resources of high-sulfur coals.

COAL EXTRACTION RESEARCH AND DEVELOPMENT

EPA has a national effort on the research, development, and demonstration of pollution control technology for mining operations. Methods and management programs are being developed for the prevention, alleviation, and abatement of all types of pollution caused by coal extraction and transportation activities. Research efforts are directed toward the assessment of new mining methods which will minimize environmental impact; this includes better preplanning and more effective mine closing techniques and other types of at-source control which will be applicable to both abandoned and active mines. Demonstration projects are initiated to determine the engineering and economic feasibility of large-scale treatment and at-source control methods. Technical reports and recommendations are provided as a basis for development of planning and implementation programs as well as provide support to other Agency programs.

UNDERGROUND MINES

The emphasis of the current program is to develop methods to dewater underground mines to prevent the flushing of acid waters. The high pyrite coals and associated overburden often result in waters with a high acid content and a low pH value. Methods being evaluated are drainage pumps surrounding the mine and located in major water-producing areas, and wells that collect water above the mine and dispose of it to an aquifer below the mine.

Several different types of mine seals have been developed to flood worked out portions of the mine and prevent air from entering after the mining has ceased. These seals are only effective in controlling acid waters under very specific conditions.

The ultimate answer to most underground environmental problems lies with the development of mining methods that prevent the discharge of acid waters upon completion of mining.

SURFACE MINES

The research program in surface mining is divided into eastern and western mining because of the great difference in the coal, climate, topography, mining methods, etc. (see Table 3). Large scale surface coal mining in the western United States in relatively new. The major effort in this area is making assessments of the environmental impacts of mining. For example, the impact on surface and groundwater, air and land productivity are being determined.

The control of erosion and sediment are of primary interest in eastern surface mines. Evaluations of erosion control methods and sedimentation basins are not being made. As a result of new federal and state mining laws, many new mining methods have been developed by industry. Environmental Assessments are being made of these.

EPA has been conducting research on eastern surface mining since the 1960's. Much information is available and thus EPA is preparing manuals of practice for the mining industry and state and federal pollution control agencies. Two of these are complete, an "Erosion Control Manual" and an "Overburden Analysis Manual". A "Premine Planning Manual" and "Revegetation Manual" will soon be published.

TREATMENT

Since acid mine drainage is a major problem at many mines, EPA has been conducting research to treat this type of water since the late 1960's. Neutralization, Ion Exchange, and Reverse Osmosis have been shown to be technically feasible. However, only neutralization has proven to be economically feasible at this time.

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PRESENT AND FUTURE ROLE OF LIGNITE IN POLISH POWER PRODUCTION AND BASIC PROBLEMS OF ENVIRONMENTAL PROTECTION

by

Władysław Witek x/

The role of lignite in the Polish power production has a strong position in respect to the quantities fired in power plants for a number of years and in produced kilowatt hours of power. Considerable contribution of lignite to the power production occurred in Poland 20 years ago with the construction of the first units (165 MW) of the Konin power-plant at the turn of the 1958/59. This contribution was at that time 5.9 percent of the Polish power production. Lignite was supplied to this power plant from the nearby Konin Mine which at that time was using only one open-pit in Gosławice.

The development of the Konin power plant (next 150 MW in 1961, and 250 MW in 1963) with the construction of the Pątnów open-pit, opened in 1962, and more importantly the construction of the power plant Turów (1400 MW) in 1962 - 1965 with the Turów open-pit (in 1963) increased the contribution of lignite in power production to 30 per-cent.

In the late sixties and early seventies this contribution achieved its peak value of 40 percent of the entire power production by Polish thermal power plants. This was achieved in newly put into operation: Adamów power plant (600 MW) with the Adamów open-pit in 1964-1967, the Pątnów power plant (1200 MW), with the new Kazimierz and Jóź-

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x/ Dr. Władysław Witek, President of Lignite Mines and Power Plants Corp. - Wrocław, pl. Powstańców Śląskich 20.

win open-pits in Konin region (in 1966 - 1969), and also due to the extension of the Turów power plant by another 600 MW. In the seventies the Polish power production by lignite - fired power plants equals 4500 MW.

In 1977 the lignite fired power plants produced about 30 billion kWh of energy which was 30 per cent of total Polish power production. During the winter peak power demand they supplied 22 per-cent of the country's requirements.

The lignite mines extracted 41 million tons of lignite in 1977, 36 million of which were delivered to the power plants. This corresponded to 27 percent of the fuel (counted by BTU) used for the production of electric energy by all industrial thermal power plants.

Apart from this large production the lignite fired power plants, contributed considerably to the technological progress in the domestic power engineering.

In 1962 the first 200 MW power rating block, with a secondary steam superheating, was installed in the Turów power plant. This fact began the construction of the whole series of 200 MW blocks in lignite fired power plants.

In the early seventies the development of new lignite mines and lignite fired power plants was stopped, and the activities were limited to maintain or increase of the production in existing mines and powerplants.

During that time the Turów power plant, due to successful modernising operations, achieved high time rate of work in more than 7000 hours per year and the local open-pit extracted much above the previous production.

That proves, that large lignite fired power plants connected with open-pits may be the principal source of electric power supply, and their work is sufficiently reliable to the requirements.

New situation in energy which occured all over the world in the middle of seventies, as well as obvious advantages of lignite as a fuel for large power plants suggest necessity of increase its contribution in the power production in Poland. Following reasons speak for the lignite utilization and extraction increase:

- considerable increase of the demand of fuel for energy production,
- large domestic deposits of lignite,
- over 30 years of experience in construction and exploitation of both surface mines of lignite and lignite-fired power plants,
- the feasibility of substituting other fuels such as bituminous coal, gas, crude oil, or nuclear fuels with lignite which considerably affects the balance of fuel import and export,
- lower costs of lignite surface extraction as compared with deep extraction of bituminous coal (in calculation per BTU) which causes that cost of electric power generated from lignite is lower by more than 20 percent than the cost of the power generated from bituminous coal,
- elimination of rail-road transport (due to joint ventures -surface mine with power plant)
- lower by about 30 percent employment in surface mines as compared with the employment in bituminous coal deep mines,
- greater security and better work conditions in lignite surface mines as compared with the conditions in deep mines of bituminous coal.

These factors determined the decision to construct in 1974-1985 the Bełchatów Mining-Power Complex which involves surface mine with production of 40 million tons /year and the power plant with capacity of more than 4000 MW. This power plant will also introduce the technological progress in Poland both considering the new construction of 360 MW blocks, and so large power output concentration in a single plant.

Realization of that task will enable the lignite industry to achieve back 30 percent of the total power production in 1985 and to reach about 50 percent in the increase of power production between 1981-85.

The investigations carried out for the last two years allowed to prepare a long term program of lignite mining and utilization development which anticipates:

- participation of lignite fired power plants in the polish electric power production of 40 percent in 1990 to 2000 what means requires about 3,5 and over 6-times increase of lignite surface mining respectively, to compare with 1977,
- participation in the total increase of new power facilities on the level of 50 percent in 1981-1985, 45 percent in 1985-1990, and 30 percent in 1990-2000 which gives the total sum of 23 000 MW.

Such a significant contribution of lignite in the future power production puts this industry on the position of one the most important factors of country's welfare.Present situation discussed above as well as projections for the future cause now and will cause many environmental protection problems which have to be solved. The main environmental elements exposed to the surface mining effects and to power production are:

- land surface
- atmosphere (mainly by the activity of power plants)
- ground water
- surface water.

LAND SURFACE

Directly converted by surface mining are open-pits areas, disposals of overburden, of coal refuse and of ashes. Transformed are also the areas assigned: for the construction of facilities, for machine assembly places, for power engineering arrangements, transportation facilities hydrotechnical constructions etc, as well as protective zones around the pits and disposals. The area presently affected by the lignite mining is about 23 thousands ha. This area will be at least doubled in next 20 years.

The area effected by negative influence of particulate and gas emissions from power plants are much larger however very difficult to estimate, due to the considerable urbanization of the country and to the emission from other pollution sources.

The greatest environmental changes occur in the pits and external disposals. These are terrains of greatly differentiated configuration, covered by heterogeneous materials with different degrees of usefulness for later utilization. In deep open-pits older and older geological formations of a significant salinity, sulphurization, and adverse physical properties are incised and removed. Additionally the differences of altitude in these post - mining terrains and external spoil disposals will increase.

Exploitation of deep deposits extends the difficulties in such terrains reclamation all the more, the application of large working and stacking machines makes difficult the selective management of the most suitable for reclamation layers.

Owing to both the size of the converted grounds and to the difficulties in reclamation of post-mining terrains following factors will become more and more important:

a) protection of agricultural and forest lands by limiting of the utilized areas,

b) protection of top soils and utilization of waste lands and poor areas for the disposals of spoils, and ashes, and also for other facilities location,

c) utilization of top soil or peat, taken from the forefront of advancing pits and disposals, for the melioration of adjoining terrains or terrains to be reclaimed.

Despite of the mentioned above growing difficulties in selective working and transportation of overburden there is a trend to utilize the lignite accompanying sands, gravels, clays and silts for various needs. It will diminish the use of agricultural and forest lands in other regions for their separate extraction.

Simultaneously with the rise of the power production based on coal, the problems of ash storage will increase. Despite of the planned greater ash utilization in industry, building industry agriculture etc., the storage of ash excesses can not be avoided. So more and more efforts and means will have to be devoted to problems of ash disposals reclamation and to the protection against harmful emission of chemical substances to soil, to water and air.

Owing to both environmental protection and economy utilization, of coal deposits with worse overburden coal ratio, preparations to gasify such deposits are carried out. Similar studies are carried out for deposits with a favourable overburden - coal ratio but where the coal is strongly salined or sulphated.

GROUND WATER

Polish deposits of lignite occur at depths of 40 to 200 m below the ground water table, and both the overburden and the layers below the deposits are saturated. Safety of mining requires therefore lowering the ground water table depth below the bottom of the exploitation. Applied drainage systems are:

- systems of underground galleries executed in coal and connected with draining holes
- systems of pumping wells, located around the pits and within them.

About 30 percent of the drainage is effected by the open pit itself.

Present and future quantities of ground water which must be pumped out from the Polish surface mines of lignite are showed below:

Year	Quantity of drained water	Average depths of required draw - down
1975	115 mil.m^3	80 m
1985	370 " "	140 m
1990	870 " "	200 m
2000	1100 " "	340 m

The offtake of such big water quantities and the depth of the drainage will cause the increase of areas where ground water table will be lowered. These areas will achieve:

in 1985 - about 1500 km^2
in 1990 - about 2500 km^2
in 2000 - about 10000 km^2.

Due to the geological conditions one must take into account that about 30-40 percent of these areas will have to change their agricultural structure. About 30 new water intakes and water supply systems will have to be built on about 50 percent of these areas by 1985, about 60 by 1990 and about 100 by 2000.

SURFACE WATER

One the most important impacts of lignite open-pit mining is effected on surface water. This influence depends on the quantity and quality of water offtaken from the mine drainage and on the required class of receiver (stream or lake) purity. These problems are controlled by appropriate regulations concerning water protection.

The main and often the only pollutant of the water drained from lignite mines are suspensions, and due to its turbidity, colour and oxygen demand. Chemical composition of these waters only seldom deviates from obligatory standards.

Technology of water purification was based on sedimentation processes in large field sedimentation basins which presently occupy totaly more than 70 hectars of land.

The expected increase of lignite production from new deposits will affect water quantity increase and quality changes. About 50-70 percent of total drainage will require a treatment. It means that about 200 mil.m^3 annually by 1980, and about 800 mil. m^3 annually by 2000 of the mine drainage will require purification.

Purification of such large quantities of water with conventional methods would require the occupation of large terrains (as big as 300 ha) for sedimentation basins construction.

Assuming the present level of suspension reduction as a satisfactory, a significant amounts of difficult to settle mineral and organic fractions, would be introduced into surface waters which could seriously disturb the biological balance in streams. So is planned to use new, more effective techniques based on application of synthetic flocculants and on biological purification by grass filter.

A separate problem is the expected deterioration of the chemical composition of water from some new mines. Waters from these mines are expected to contain large amounts of salt.

There is lack, so far, of effective methods for purification of large water amounts with the average or low salts' concentrations. Having this in view we plan to diminish harmful effects of such water on environment by construction of storing - dosing reservoirs. It enable control of the saline water discharge. Thus, permitted concentrations of mineral could be controlled in receiving streams.

FINAL REMARKS

Our considerations above showed that the lignite surface mining would be one of the main power production sources in Poland during the next twenty years.

Extraction increase will require adopting new terrains, and will cause changes in the natural environment. Therefore these problems are now of our central interest and will be require much effort in future. Environmental protection studies, carried out in cooperation with the US EPA, well serve this purpose and so do international meetings such as our today conference.

LEGISLATION AND REGULATIONS CONTROLLING COAL EXTRACTION AND CONVERSION IN THE UNITED STATES

by

Roger L. Williams[x]

INTRODUCTION

Delegates to the Symposium, respected scientists, and, above all, friends, I'm pleased to speak to you about our common interests. I'm also honored to have been invited to your wonderful country, and to experience first hand the fascinating combination of European charm and modern technological advances that exist here. I am especially looking forward to learning more about surface coal mining and reclamation in Poland. The respect you have for the post-mining condition of your lands is invaluable. I know that EPA has learned a great deal with your help over the past six years.

I appreciate the complex environmental issues that confront you in developing the large open cast mines and underground mines most of which are much larger than in the United States. Hydrologic systems, land use systems, and biological systems are affected by surface mining and to varying degrees by underground mining. When reclamation is poorly done there are far-reaching effects into the social and economic well-being of a country. Such effects were not really recognized in the United States until the late 1960's. In response to this new-found concern, a number of the States began the long and often tedious job of updating their regulations controlling the adverse environmental effects of coal mining.

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x/ Roger L. Williams, Deputy Regional Administrator, U.S. Environmental Protection Agency.

HISTORY

Prior to 1920, strip mining for coal was occasionally practiced while reclamation was nearly unheard of. Strip mining of coal began to expand rapidly in the 1920's and 1930's and some reclamation was practiced where a return of investment was clearly recognized. During this same period degradation of land and water by coal strip mining grew rapidly. Local concern surfaced during the period and was met by small remedial mine drainage control projects conducted by the Civilian Conservation Corps (CCC) and the Works Progress Administration (WPA) programs.

In late winter of 1939 a heated debate over strip mining took place in the central Appalachian region. Should strip mining be prohibited? The acid-laden and lifeless streams were commonplace. The mountainsides were beginning to exhibit the scars of unreclaimed contour strip mining. Debate in the West Virginia Legislature was strong in favor of outright prohibition of strip mining, and on March 6 of that year the West Virginia House of Delegates overcame a last-minute effort to table debate and passed House bill 390, "A bill to promote and preserve the public health and welfare by prohibiting the strip mining of coal". The vote was 69 yeas to 15 nays. Almost at the same time the West Virginia Journal of the Senate was considering legislation to "regulate", as opposed to "prohibiting", strip mining, and on March 10 passed a regulatory bill by unanimous vote. One day later, on March 11, 1939, the West Virginia House of Representatives amended its bill to coincide exactly with the Senate bill and, by a vote of 65 to 4, enacted the Nation's first state strip mining law.

- --Six other states enacted similar laws during the next 16 years.
- --The environmental Problems of coal mining in Appalachia received national attention in 1963 with the publication of Harry Caudill's book,

Night Comes to the Cumberlands

In 1965 our National Congress, reacting to increasing national concern, authorized a national study of the effects of surface mining with the passage of the Appalachian Regional Development Act.

In 1967 the Department of the Interior published the study entitled "Surface Mining and Our Environment", which called for a strong national regulatory program and a program to restore abandoned, unreclaimed mined lands.

In 1968 the Administration proposed to the National Congress the Surface Mining Reclamation Act providing for a strong Federal - state regulatory program to control strip mining. The Senate held 3 days of hearings but took no further action.

By 1970, 23 states had enacted legislation to control surface mining activities.

In 1971 the Administration again proposed a revised Mined Area Protection Act which would have regulated both surface and underground mining. Again, Congress did not enact legislation, although the House of Representatives did pass a bill.

On August 3, 1977, 38 years after the first state reclamation law was enacted and following 10 years of heated debate in the National Congress, President Carter signed the Surface Mining Control and Reclamation Act of 1977 which is designed to establish national standards that ensure coal mining and reclamation in a manner that minimizes environmental damage. I will discuss that Act in a moment.

There are additional national laws in the United States that impact coal mining and processing in the United States. These include three major laws,

- The National Environmental Policy Act of 1969
- The Clean Water Act and
- The Clean Air Act.

NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act (NEPA) requires Federal agencies to develop and implement environmental evaluations of major actions they propose to take that might adversely affect the human environment. Implementation of the Act has generally been in the form of preparation of internal documents such as environmental assessments and more widely distributed documents called "environmental impact statements".

Whenever federally owned coal, which comprises the majority of the coal in the West, is proposed to be leased or mined, the federal government will be faced with potentially major decisions generally subject to the provision of the NEPA. The Agency must then examine the existing environments, the impact of the proposed action on that environment, and alternatives to the proposed action if the effects are adverse.

The purpose of the environmental impact statement is to provide full and fair discussion of significant changes that may occur as a result of the proposed action. This discussion is then made available to decision makers and the public as a whole. It is most important that these analyses identify alternatives to or modifications of the proposed action that would minimize adverse impacts.

A few States require the same sort of analysis. In one western state, this environmental review resulted in protection of a significant surface drainage channel and flood plain and in the recovery of millions of tons of coal more than was initially proposed by the operator. So there may be direct benefits to both coal mining and the environment in this process.

CLEAN WATER ACT

The Clean Water Act specifies environmental requirements administered and enforced by EPA and the state. The Clean Water Act requires control of point source discharges from all industrial and municipal facilities including active coal mines; requires environmental evaluations of dredging or filling operations prior to any approvals; and requires comprehensive planning for nonpoint sources of pollution. More specifically, surface water discharges from active surface and underground mines must meet the following water effluent standards, or more stringent standards established by individual states:

Table 1 Best Practicable Control Technology Currently Available (BPCTCA) Coal Preparation Plants and Associated Areas

pH 6.0 or Fe 10 mg/l
(In milligrams per liter)

Effluent Characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed
Iron, total	7.0	3.5
Manganese, total	4.0	2.0
TSS	70.0	35.0
pH	Within the range 6.0 to 9.0	

pH 6.0 or Fe 10 mg/l
(In milligrams per liter)

Effluent Characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed
Iron, total	7.0	3.5
TSS	70.0	35.0
pH	Within the range 6.0 to 9.0	

Table 2 Best Practicable Control Technology Currently Available

Coal Mines
pH 6.0 or Fe 10 mg/l
(In milligrams per liter)

Effluent Characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed
Iron, total	7.0	3.5
Manganese, total	4.0	2.0
TSS	70.0[1/]	35.0
pH	Within the range 6.0 to 9.0	

1/ These TSS effluent limitations shall not apply to discharges from coal mines located in the following States: Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming. In these States, TSS limitations shall be determined on a case-by-case basis.

pH 6.0 or Fe 10 mg/l
(In milligrams per liter)

Effluent Characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed
Iron, total	7.0	3.5
TSS	70.0[1/]	35.0
pH	Within the range 6.0 to 9.0	

1/ These TSS effluent limitations shall not apply to discharges from coal mines located in the following States: Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming. In these States, TSS limitations shall be determined on a case-by-case basis.

These standards are designed to be followed by the States. Those States qualified to implement this water quality control program my, and often have, developed more stringent standards.

SURFACE MINING CONTROL AND RECLAMATION ACT

The most important national legislation which can ensure a substantial degree of protection from the potentially adverse environmental impacts of coal mining is Public Law 95-87. This new law is titled the "Surface Mining Control and Reclamation Act of 1977". The law has numerous purposes, but the ones of greatest importance to this discussion are the following:

- to establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations;
- to assure that surface mining operations are not conducted where reclamation as required by this Act is not feasible;
- to assure that surface coal mining operations are so conducted as to protect the environment; and
- to assure that adequate procedures are undertaken to reclaim surface areas as contemporaneously as possible with the surface coal mining operations;

The "Surface Mining Control and Reclamation Act" (SMCRA) is basically designed to ensure that coal mining is conducted in a manner that minimizes adverse impacts on the hydrology of an area. Yes, it includes wildlife protection, blasting controls, and revegetation requirements, but the emphasis is on protection of the hydrologic system. Quite frankly, much of the legislative history includes testimony on control of adverse hydrologic impacts of western coal mining. The Act applies to both surface and underground mining State Delegation:

Before proceding to examine environmental protection performance standards of the Act and the federal regulations developed to apply the Act, one more purpose of the Act is important to this discussion. That purpose is to assist the States in developing and implementing a program to achieve the purposes of this Act.
The thrust of the SMCRA is to assist the states in developing programs

judged to qualify the states to assume exclusive jurisdiction for coal mining regulatory activities designed to protect the environment. There are at least four different ownership arrangements which affect the regulatory authority over western coal. The coal can be privately owned, Indian owned, or federally owned. The state has had jurisdiction over the first two and will continue to under the SMCRA if it develops an approvable regulatory program. With such a program, the state will also have initial jurisdiction over environmental matters affected by development of federally-owned coal though the federal government will retain final mine plan approval authority for federal coal. If a state does not develop an adequate regulatory authority, then environmental regulations for all coal mining and reclamation will be the exclusive jurisdiction of the federal government.

Regulatory Framework:

The Surface Mining Control and Reclamation Act provides for all of the usual and traditional mechanism for the administration and monitoring of extraction activities such as:

- permit application and issuance
- reclamation plans
- performance bonds
- monitoring requirements and
- enforcement, etc.

I will not discuss these as they are fairly straight forward. However, I would like to briefly discuss an important and unique, at least in the USA, requirement and then go into more detail on the specific, on site, reclamation requirements and performance standards.

The unique requirement that I'm referring to is a very important procedure that allows the designation of lands as being unsuitable for surface coal mining. Under this authority the State is to establish a planning process, based on federal criteria, that enable objectives and sound discussion, as to what lands in a particular state should not be surface coal mined. The criteria for designation include:

- reclamation is not technologically or economically feasible
- incompatible with state or local land use plans
- fragile or historic lands
- loss of long range productivity and
- endanger life and property

Performance Standards:

In terms of the ultimate goal of reclamation, the regulations require: (1) a determination of the premining use of the land that is proposed to be disturbed, (2) an identification of the premining land use category, and (3) if the land use category is to be changed, use of a set of criteria to determine if the proposed post-mining land use meets the standards of the Act. This is essentially a planning procedure.

The performance Standards require:

1. Grading to an "approximate original contour".

2. Control disposal of spoil which is excess to achieving approximate original contour, that is, disposal in areas other than that mined. Requirements are divided into two sections, one for disposals which do not encroach on natural drainage channels and one for those that do. The more stringent performance standards are contained in the latter section where so-called "head-of-hollow" or "valley" fills are addressed. Here there are requirements for rock drains, diversion of drainage, controlled placement of fill, and terracing.

3. Specifies (a) topsoil removal in terms of essential horizons and thicknesses, (b) topsoil redistribution, and (c) topsoil storage. The section also allows the use of alternative strata if the resulting soil medium is demonstrated to be more suitable for restoring land capability and productivity. The regulations provide that "where the removal of topsoil results in erosion that may cause air or water pollution, the regulatory authority shall limit the size of the area from which topsoil may be removed at any one time and specify methods of treatment to control erosion of exposed overburden.

4. Protection of the hydrologic system. This hydrologic system protection section of the Act is considered by many to be the critical

section. It is the broadest requirement of the initial regulatory program. It also authorizes the regulatory authority to take "other actions" necessary to minimize disturbances to the prevailing hydrologic balance both on and off the mine site.

5. That all surface drainage from disturbed areas must pass through sedimentation ponds and that any discharges therefrom meet effluent limitations. (which are essentially the same requirements mentioned in Table 2 as provided in the Clean Water Act).

6. That all runoff from storms up to that resulting from a 10 year-24-hour storm be controlled. The surface water monitoring provisions of the regulations require the development of an adequate water flow and quality monitoring system and routine reporting of data. Diversions are encouraged to the degree necessary to keep water away from disturbed areas and thus there are no quantitative effluent limitations that apply. Rather the diversions are to be designed, constructed, and "operated" in a manner that prevents additional contributions of suspended solids to the extent possible, using the best technology currently available. The standard for temporary diversions of overland flow has been reduced to a 1-year event. A one-hundred-year event is used for permanent diversions. Streams can be diverted only if the average stream gradient is maintained and the channel is designed to be stable. The regulations also require that any coal mining and reclamation activities conducted within 100 feet of the stream channel receive special authorization.

7. Provide guidance on area and depth of ponds, retention time, sediment storage, and credits for upstream sediment controls.

8. Provide for ground water protection. Reclamation to restore "aaproximate pre-mining recharge capacity", is required, as is ground water monitoring. Thus the effects of surface mining on the ground water system are acknowledged and are to be mitigated or avoided.

9. Address an agricultural phenomena - the "alluvial valley floor" of the interior western United States. Those alluvial valley floor areas determined to be of significance to agriculture are essentially excluded

from surface mining of coal. If alluvial valley floors are mined, their essential hydrologic functions must be preserved.

10. Require that plans for permanent impoundments show probable future compliance with criteria developed to ensure that the impoundment would serve a useful purpose rather than be a shortcut to release of a reclamation bond. The regulations require coal waste piles to be constructed with a margin of safety under various stability conditions.

11. Specify limitations on the impact that explosives may have, generally on any dwelling within one-half mile of the blasting area. More specifically, the weight of explosives fired is limited to that causing a maximum peak particle velocity of the ground motion of 1 inch per second and to that causing an air blast of 128 decibel (linear peak) at any structure within one-half mile outside the permit area.

12. Lastly, they implement the revegetation requirements of the SMCRA. It requires that a vegetative cover consisting of diverse, effective, and permanent species be established, generally in comparison to site-specific, premining vegetation surveys. Revegetation success is to be measured on the basis of the approved seeding procedures producing a ground cover of at least 90 percent of that measured in the site-specific, pre-mining, vegetation surveys.

CLEAN AIR ACT

The Clean Air Act, a principal authority behind EPA's air quality control activities controls emissions from both coal conversion facilities and from coal mines. It is thus an appropriate finale for this discussion since I have not mentioned controls over coal conversion facilities to date.

Fugitive dust from coal mines has received new attention as a result of the 1977 amendments to the Clean Air Act. The Clean Air Act contains requirements for EPA to administer and enforce along with the

States. Recently promulgated regulations (June 19, 1978) require that fugitive dust from surface mines be controlled using the Best Available Control Technology (BACT) if the mine has the potential to emit 250 tons per year or more. This requirement is in the context of reviews of stationary sources of air pollution to prevent significant deterioration of air quality. Based upon recent measurements, any western coal mine producing more than 500,000 tons per year would likely "qualify" for review. A qualifying surface or underground coal mine must then apply best available control technology for particulates unless the increase in allowable emissions of that pollutant would be less than 50 tons per year. Once it is determined that an applicant wishing to construct a surface coal mine will employ whatever controls are determined to be BACT for the operation, the remaining nonfugitive dust emissions are modeled to predict the resulting air quality impact. The burden of showing to what extent emissions from a proposed or modified coal mine would be made up of fugitive dust rests with the operator. Specified incremental concentrations depending upon the natural of the location (e.g. National Parks) must not be exceeded. Also, in no case may the actual concentration exceed the national secondary ambient standards of 60 ug/m^3 (annual geometric mean) and 150 ug/m^3 (24-hour maximum not to be exceeding more than once per year).

BACT for fugitive dust determinations are to be made on a case-by-case basis by the reviewing authority taking into account such factors as cost, energy, and technical feasibility. BACT's may be a design, equipment, work practice or operational standard if imposition of an emission standard is infeasible.

Air quality Standards of Performance have been established for coal preparation plants. The standards are:

Table 3 Coal Preparation Plant Emission Standards

Emission Source	Particulate Concentration	Opacity
Thermal dryer	0.070 g/dscm	20 %
Pneumatic coal cleaning	0.049 g/dscm	10 %
Coal processing, conveying, storage, transfer or loading		20 %

The operations must be monitored after construction.

EPA and State air quality control agencies have a major role in siting coal-fired power plants and will continue to have a strong role in any other coal conversion facility. I will only briefly discuss the pertinent environmental controls.

The EPA has established standards of performance for coal-fired power plants. These standards control the following in pollutants and are measured at the power plant stack (chimney).

Table 4 Coal-Fired Power Plan to Emission Standards

Pollutant	Emission Limit
Particulates	0.1 pounds per million BTU heat input
Sulfur Dioxide	1.2 pounds per million BTU heat input
Nitrogen Oxides	0.7 pounds per million BTU heat input

These standards in general require 99.0 + percent control for particulates, some flue gas desulfurization (depending upon the sulfur and heat content of coal) for SO_2, and good combustion design for NO_x. National Ambient air quality standards have been established to protect human health and welfare. These standards are given in Table 5.

Table 5 National Ambient Air Quality Standards

		Concentration, ug/m^3	
	Averaging Time	Primary	Secondary
Sulfur dioxide	Annual	80	60
	24 hour	365	260
	3 hour	-	1300
Particulate	Annual	75	60
	24 hour	260	150
Nitrogen Oxides	Annual	100	100
Ozone	1 hour	160	160
Carbon Monoxide	8 hour	10,000	10,000
	1 hour	40,000	40,000

Requirements have also been established to protect clean air areas such as national parks and wilderness areas. Incremental Ambient air quality limits for particulate and sulfur dioxide are shown in Table 6.

Table 6 Incremental Ambient Air Quality Limits

Pollutant	Maximum allowable increase (micrograms per cubic meter)
Class I	
Particulate matter:	
Annual geometric mean	5
Twenty-four hour maximum	10
Sulfur dioxide:	
Annual arithmetic mean	2
Twenty-four hour maximum	5
Three-hour maximum	25
Class II	
Particulate matter:	
Annual geometric mean	19
Twenty-four hour maximum	37
Sulfur dioxide:	
Annual arithmetic mean	20
Twenty-four hour maximum	91
Three-hour maximum	512
Class III	
Particulate matter:	
Annual geometric mean	37
Twenty-four hour maximum	75
Sulfur dioxide:	
Annual arithmetic mean	40
Twenty-four hour maximum	182
Three-hour maximum	700

The review mechanism is to perform computer modeling prior to the construction and operation of a facility in order to judge the potential compliance with the appropriate ambient concentrations.

FINAL REMARK

I hope that this general introduction into applicable environmental regulation affecting coal mining in the United States has been helpful. I would be glad to answer any question that you may have.

LEGISLATION, LAWS AND REGULATIONS CONTROLLING THE SURFACE MINING OF LIGNITE AND ENVIRONMENTAL PROTECTION IN POLAND

by

Roman Kraus x/

INTRODUCTION

Mining is in Poland one of the main branches of industry. Annual extraction of various raw materials and minerals has already passed the 500 million tons mark, of which nearly 300 million tons was extracted by surface mining methods. One of the more important directions of surface mining activity is the extraction of lignite, amounting to 41 million tons per year which requires the removal of about 150 million m^3 of overburden.

At least a fourfold increase in the extraction of lignite is expected in the next 20 years.

The geological structure of deposits, the technology of exploitation and the enormous extent of operations required a regularization of mining activity with a number of laws and regulations governing the routine of preparation and of performance of mining operations, safety at work, and also the issue of the influence exerted on the environment. This influence concerns equally land surface, surface water, ground waters and, to a smaller extent, the atmosphere.

The large variety of mining operations methods and the above mentioned impacts on the environment suggests that a wide range of compulsory regulations, must be taken into account to suit the activities,

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x/Roman Kraus, M.Sc. Chief Engineer- POLTEGOR, Rosenbergów 25, Wrocław starting with issues of land ownership through to problems of safe performance of exploitation work, and ending with the returning of terrains in good conditions to their original owners. If must be emphasized that 75 % of land in Poland is privately owned.

In order to present the issues considered in the latter part of this report more clearly, the structure of the governing bodies in Poland should be presented.

The legislative and controlling authority is Parliament, elected in General Elections, and the Council of State with its presiding Chairman, elected by Parliament. The government constitutes the executive power, consisting of a Prime Minister and Ministers appointed by Parliament; from this group is appointed a Cabinet presided by a Prime Minister the Chairman of Cabinet.

The Ministers direct the departments entrusted to them as well as the heads of Central Offices (Agencies) appointed for specific fields such as the Central Office for Geology, the Bureau for Mines (Bureau of Mines supervises all mining operation in the country), etc.

Acting within the jurisdiction of the Chairman of the Cabinet is the State Board for Mining appointed in accordance with the Mining Law. Within Board's jurisdiction is the preparation of advice and opinions regarding methodology of the rational exploitation of deposits, as well as advice on proposed regulations for different minerals and different mining methods.

Besides the central authorities, there also local administrative authorities.

The territory of Poland is divided into 49 administrative regions (voivodships) subdivided into communes. At the head of these units are National Councils at appropriate levels elected in General Elections. The Voivodes (head of administrative regions) appointed by the Chairman of the Cabinet, and the Heads of Municipalities are appointed by the Voivodes.

Industry in Poland is entirely state owned, and operations in this area are conducted by state enterprises supervised by intermediate bodies, such as corporations or groups of enterprises.

The extraction of bituminous coal is controlled by the Ministry for Mining, through regional corporations. The extraction of lignite is supervised by the Ministry of Power and Atomic Energy through the Lignite Mines and Power Plants Corporation, which also controls power plants operating with lignite.

INSTITUTIONS PARTICIPATING IN DRAFTING OF LAWS AND REGULATIONS REGARDING MINING ACTIVITY AND ENVIRONMENTAL PROTECTION

Dependent on onis field of reference could be distinguished:

i) the laws
  - the laws passed by the Parliament of Polish People Republic,
  - the decrees issued by the State Council,

ii) the regulations
  - the regulations issued by Cabinet, the Ministers, the Heads of Central Offices (i.e. the bodies of central administration),
  - the ordinances issued by Voivodes and Voivodship councils, (i.e. the bodies of regional administration,
  - the ordinances, instructions, guidelines and standards issed and established on various administrative levels.

Beside the Mining Law the mining activity and related to regulations protection of natural environment are in force regulations issued by the Ministers of:

- Mining and Power Industry[x/]
- Power and Atomic Energy
- Mining
- Forestry and Wood Industry

[x/] From the year 1976 divided into the Ministry of Mining and the Ministry of Power and Atomic Energy

- Agriculture
- Municipal Attains xx/
- Administration, Local Economy and Environmental Protection.

Additionally in the area of mining (other than coal) the following Ministers also participate in the supervision and regulation of mining activities:

- Metallurgy
- Building and Building Materials Industry
- Transport.

All mining operations must follow the regulations extablished by the Chairman of Bureau for Mines.

INSTITUTIONS' FUNCTIONS IN THE ISSUANCE OF LAWS AND REGULATIONS

As mentioned in the preceding chapter, the Parliament of the Polish Peoples Republic passes laws of State-Wide application, while the State Council issues Decrees, which have a similar (for less essential problems) scope, but are issued between Sessions of Parliament. Decrees have the same legal force as laws.

The Cabinet of the Government formulate regulations which form a basis for later ministerial orders, and executive orders or have a nation wide or inter-ministerial character.

The Ministers, however, issue executive regulations and ordinances with legal force in a given ministry, or nation-wide if the given ministry has exclusive jurisdiction in a given subject matter.

This concerns also various kinds of instructions and guide-lines.

The Bureau of Mines, subordinated directly to the Chairman of Cabinet, controls the entire national mining activity in the field of proper performance of operations, and the correct management in deposit; it issues in this matter detailed regulations binding in all mining undertaking.

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xx/ Transformed into the Ministry of Administration, Local Economy and Environmental Protection

THE MORE IMPORTANT ACTS RELATING TO MINING OPERATIONS AND ENVIRONMENTAL PROTECTION

Basic documents relating to mining operations including lignite extraction, are:

a) The Laws

- The Mining Law passed by the Parliament in 1961, with amendments in 1971, 1977 and 1978, determines useful minerals (contained in natural deposits and being subject to this law), the principles and conditions of their extraction and the accomplishment of geological work connected with mining operations, it regulates matters of designing, constructing, and dismantling (liquidation) of a worked out mines and constructions on mining terrains, also protection of mined terrains, as well as the responsibility of Bureau of Mines and other organisations in this matter.
- Water Law - approved by the Parliament in 1974, defines the property of waters, the principles of issuance of water permits for water utilization, the protection of water, also flood control principles of hydrotechnical works; it determines also the rules and forms of activity of water companies, the keeping of books and all aspects of water management.
- Construction and Building Law is a Parliament act of 1974 regulating activities regarding the land use in accordance with settlements local plans for terrain utilization, the design, construction, maintenance and the demolition of constructions; it defines the rules for state and local administration bodies in in these fields.

Owing to the limitations of size of paper for the regulations cited below, reference is confined to their designations and the year of their issue only, nonetheless their designations allow us to infer their contents:

- the act of 1961 regarding economic planning of areas

- the act of 1966 on air protection
- the act of 1971 on protection of arable and forest lands and on reclamation of disturbed terrains
- the act of 1973 on reforestation.

b) decrees and resolutions of the Council of Ministers

- of 1970 on the protection of forests against impacts of harmful dusts and gases emitted by industrial works
- of 1963 regarding the compensation for damages incurred by the effects of mining operations on the sowing of crops, for irreparable damages to arable and forest lands, and in matters of remunerations for mining damages
- of 1966 in matters of permissible concentration levels of substances in atmospheric air
- of 1976 in matters of standards of permissible pollution levels in waters, and conditions of waste waters discharge to surface waters and to the ground
- of 1972 in matters of detailed rules for reclamation and restoration of lands
- of 1975 in matters of water classification, of conditions which waste waters should fulfil and of penalties for the infringements of these standards
- of 1976 in matters of operations and activities, the performance of which is forbidden in the neighbourhood of water-works.

c) Regulations of the Chairman of the Cabinet

- of 1965 in matters of safety and work hygiene as well as fire hazards in surface mining
- of 1971 in matters of acquisition, storage and use of explosives in mining operations

d) Regulations of the Chairman of Bureau of Mines

- of 1967 in matters of preparation and of sanctioning plans of mining operations (with riders added to it in 1973 and 1976)
- of 1970 in matters of criteria of estimating water hazards and of principles and methods of estimating mineral deposits or their parts included in particular hazard zones
- of 1971 - executive regulations in matters of acquisition, storage and use of explosives in mining operations.

e) Regulations of Ministers

- of Agriculture and of Forestry and Wood Industry of 1972 in matters of determination of arable and forest lands threatened with erosion, with rules and procedures for control erosion
- ordinance of the Forestry and Wood Industry of 1976 in matters of inclusion and of exclusion of State owned forestry lands and in changes of forest cultivation to a different type of utilization.

f) Ordinances of Ministers:

- of Mining and Power Industry of 1975 complementing "Detailed principles of operations performance and management of lignite deposits in surface mines (issued in agreement with the Chairman of the Bureau of Mines)
- of Mining and Power industry of 1972 in matters of reclamation and restoration of postindustrial terrains and of afforestation within the Ministry of Mining and Power Industry
- of Agriculture and Communal Economy of 1969 in matters of terrain inventory
- of Agriculture and Forestry and Wood Industry of 1974 in matters of maintaining a register of terrains subjected to reclamation and restoration
- of Forestry and Wood Industry in matters of rules the calculation of compensation for premature cutting down of forrests

- of Power and Atomic Energy of 1976 in matters of environmental protection and work hygiene in the years 1976-1980.

From the above it appears that the considerable number of legally binding acts makes impossible their wider discussion within the framework of this presentation.

Independently of the regulations, there is a great number of compulsory instructions and guidelines concerning particular issues. In the mining of lignite, similarly as in other fields of industry, there are many state and departmental standards in force.

DIVISION OF JURISDICTION FOR OF EXECUTION AND CONTROL IN THE FIELD OF MINING AND ENVIRONMENTAL PROTECTION

As evident from the previous chapter, in the last few years a particular emphasis hasbeen placed on the safety of work and environmental protection on industrial operations, and on mining in particular. The jurisdiction of particular bodies in the field of execution and control were clearly definated.

In chapter 2 ministries controlling particular divisions of mining of Poland are same. They have a similar type of jurisdiction, namely the control of correct operations and the development of minign in accordance with domestic demand for particular raw materials mined.

The Bureau of Mines fulfils its controlling function through the Regional Offices of Mines, localized in regions with intensive mining activities, namely in Bytom, Częstochowa, Gliwice, Katowice, Kielce, Kraków, Krosno, Lublin, Poznań, Rybnik, Sosnowiec, Tychy, Wałbrzych and Wrocław. The Regional Offices operate in the areas assigned to them (the whole territory of the country being under their supervision). The following are included in their sphere of activity:

- protection of the public interest, public health and of human life
- control of mine operations, and the protection of land surfaces within the mined areas from needless devestation in the course these operations

- inspection of lands undergoing reclamation, or involved in reclamation activity
- approval of plans for mine operation, and reclamation and their control.

As a sidenote, it is worth mentioning that the plan for mine operations is a fundamental document, on the basis of which every mine works. Such plan, as a rule, is prepared for two years, and comprises details of mine operations in this period, with a description of all relevant elements.

Within the jurisdiction of the Voivode, and therefore, of a body of regional administration on a higher level belong the following:

- cooperation in the elaboration of programs and plans of region development together with environmental protection and suggestions on proposals on the siting of establishments
- control of the rational utilization of land and the protection of arable and forest lands
- control of industrial enterprises in the area of environmental protection
- investigation and assessment of the state of environment
- issuing water permits for use of water and for discharge of waste waters
- coordination of all operations connected with environmental protection
- coordination of investments, to be developed in his area of activity.

The jurisdiction of the head of the Municipality, and so of a regional unit of lowest status, can be described as follows:

- the determination of the direction of use with indication of responsible persons
- record keeping of land subject to reclamation,
- the approval of reclamation designs
- the assignment of deadlines for detail reclamation execution
- the inspection of reclamation activity.

Apart from this it is worth mentioning jurisdiction of the Ministry of Forestry and Wood Industry which

- takes decisions regarding the exclusion of terrains from State-owned Forestry lands; it also determines the amounts of payments and dues for the acquisition of arable and forest lands without standing timber
- coordinates both the research an the field of economic utilization of reclaimed lands, and the realization of this land reclamation.

CONCLUSION

The resport's objective was to present the state of legislature regulating lignite surface mining and environmental protection in Poland. As can be seen, the majority of legal acts in force also concern other divisions of mining and even the entire industry. These had to be mentioned all the same.

In conclusion it is worth mentioning one more initiative, whose objective is to raise the standard of reclamation in Poland. The problems connected with it area regulated by a number of legal acts, the engaged employees therefore having a great number of relevant formal obligations, independent of problems of merit. For this reason a few years ago research was undertaken in Poltegor few and completed this year with the title "Guidelines for the reclamation of terrains transformed by industrial activity". This is report - manual in which participated many specialists and scientists from various fields. The coordination of the whole project took place in POLTEGOR. These guide-lines constitute a kind of manual for people engaged in designing, organizing and executing reclamation work. It contains, apart from the set of rules governing these problems, instructions regarding the organization of operations and ways of financing, and also the essential solutions of problems pertinent to all divisions of Polish mining, and to waste disposal from power plants.

This manual will shortly be disseminated in the country.

EPA ENFORCEMENT AND NEW SOURCE SURFACE MINING REQUIREMENTS AND APPLICATION IN WEST VIRGINIA, USA

by

Stephen R. Wassersug[x/]

INTRODUCTION

It is with great pleasure that I have this opportunity to speak at this fine symposium, to visit once again your beautiful country, and to meet with colleagues and friends. I will be discussing the Environmental Protection Agency's (EPA) enforcements and their application in West Virginia.

Enforcement

EPA was created by Congress as a regulatory agency; as such, a fundamental mission is to enforce the environmental laws created by Congress. EPA has over 10,000 people with over 20% directly responsible for enforcing EPA laws. When Congress passes a law, EPA is responsible for further defining of those laws by developing appropriate regulations, guidelines, and standards. Often, perhaps more often than not, these regulations and standards are challenged in the U.S. Federal Courts by concerned people. Environmental citizen interest groups often feel that our regulations are not stringent enough, while industry might feel they are too stringent. Often, the same regulation is challenged by

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[x/] Stephen R. Wassersug, Enforcement Division Director, U.S. Environmental Protection Agency, Region III, Philadelphia 19106.

Table 1

Surface Mines

Existing Effluent Limitations and Monitoring Requirements[a]

Effluent Characteristic	Discharge Limitations		Monitoring Requirements	
	Daily Average	Daily Maximum	Measuring Frequency	Sample Type
Flow - M_3/Day			Two per month	Measured
Iron, Total	3.5 mg/l	7.0 mg/l	Two per month	Composite
Manganese, Total	2.0 mg/l	4.0 mg/l	Two per month	Composite
Total Suspended Solids	35.0 mg/l	70.0 mg/l	Two per month	Composite
At all times Alkalinity shall be	Greater than Acidity		Two per month	Grab
At all times Acidity shall be	Less than Alkalinity		Two per month	Grab

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored twice per month by a grab sample.

[a] 40 CER Part 434, Federal Register Vol. 42, No. 80. Tuesday, April 26, 1977.

Proposed Standards of Performance for New Source

Surface Mines[b]

Effluent Characteristic	Discharge Limitations	
	Daily Average	Daily Maximum
Iron, Total	3.0 mg/l	3.5 mg/l
Manganese, Total	2.0 mg/l	4.0 mg/l
Total Suspended Solids	35.0 mg/l	70.0 mg/l

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored twice per month by a grab sample.

[b] 40 CFR Part 434, Federal Register Vol. 42, No. 181, Monday, September 19, 1978.

both groups for these reasons, and our Federal Courts must interpret of technological infeasibility or where it is felt that the standard will not adequately protect health, fish, wildlife, drinking water or other areas. Some of these court challenges might take years before final resolution, while EPA may be restricted from enforcing the regulations during the period of challenge.

EPA attempts to actively pursue all violations of its environmental laws. In fact, it is EPA's policy to enforce against all major violating dischargers of air and water pollution including mines and power plants. Further, it is EPA policy that all such violators pay penalties commensurate with the economic gain obtained by violating pollution control requirements. Table 1 denotes technology standards required to be met by surface mines in 1977. Failure to install, operate and maintain the proper control equipment will require EPA to institute its penalty policy. The penalties will be based on the cost of equipment and operation, maintenance costs, cost of any environmental harm and willfullness of the violators not to comply. However, the total penalties can be offset by a partial credit where the violator now agrees to install pollution control equipment greater than necessary to meet the standard.

The penalty policy was designed to ensure that the few violators were properly penalized since over 80% of the industries voluntarily committed large resources to meet the requirements of Federal laws. If widespread voluntary compliance is to continue, violators must not gain benefit from noncompliance. Also, it is important that industry recognize that the Federal policy is uniform in the United States. The Clean Water Act authorizes penalties up to $10,000 per day and the Clean Air Act $25,000 per day including possible jail sentences.

New Source Surface Mining Requirements

The remainder of my discussion will focus upon opening new surface mines in West Virginia and compliance with EPA requirements. As the demand for coal increases, states like West Virginia are pressured to ignore environmental concerns over energy demands. Table 2 denotes

Table 2

Coal Mining in West Virginia[1]

	Total	Surface Mining	Other Facts
Mining Employment	55,000	6,600	48% of nation's coal exports from West Virginia
Coal Reserves[2]	39,590 million tons	5,212 million tons	Most lands for mining have slopes greater than 25 %
Tonnage Per Year	109,000,000 T/y	20,000,000 T/y	Land reclaimed since 1961 is 206,000 acres
New Coal Mines	300 per year		70 % consumed in power plants
Mines less than 100,000 T/y	90 %		16.5 % of the coal from 79 % of the mines
Mines more than 100,000 T/y	3 %		
Sulfur range	< 1.5% - > 3%		
Low	54% Southern West Virginia		
Medium Sulfur	31%		
High Sulfur	15% Northern West Virginia		

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[1] Most data based on 1974-75 figures and extracted from Final Report on Environmental Aspects of the New Source NPDES Permit Program for the West Virginia Surface Coal Mining Industry, 1977-1980

[2] Based on current mining techniques.

compilation of summary coal mining data for West Virginia.

For a new mine to open, a permit from EPA must be issued, allowing the discharge to a body of water. This National Pollutant Discharge Elimination System (NPDES) permit is also required of existing dischargers where there is a point source. This permit is probably similar to Poland's Water Rights Permit. Proposed new Source surface mining requirements (table 1) will require the coal mine operator to meet the standards upon commencement of operation.

Of great concern to the Government, the coal mine operator, and citizen is the requirement for a detailed environmental review. Under the National Environmental Policy Act (NEPA), a major Federal action, like issuing a permit, requires that an environmental assessment of the action first be prepared and considered. All aspects of the environment must be reviewed, including land use planning, alternative site options, effects to the air and water, reclamation, waste noise, and related impact upon the infrastructure. When Congress first passed this law in 1970, no one realized its full impact. The law, through the environmental assessment and impact statements, has at times been responsible for slowing or stopping development of highways, dams, etc., while leading to sound environmental programs.

Where the environmental assessment shows no negative environmental effects, EPA will prepare a negative declaration and the project could proceed. However, if the environmental assessment indicates potential negative environmental impacts, an environmental impact statement is then prepared. The results of this statement and significant citizen interaction might then lead to abandonment or continuation of the Federal action or selection of an alternative action with less environmental consequences.

West Virginia Surface Mining

As noted in table 2, some 300 new coal mines open each year. To comply with NEPA it is necessary to compile substantial information on West Virginia mining and to recommend an approach for dealing with the environmental assessments. A consultant working with EPA undertook a study "Environmental Aspects of the New Source NPDES Permit Program for the West Virginia Surface Mining Industry". Information in this report includes:

1. Surface mineable coal resources
2. Geographic distribution
3. Geological occurrence of surface mineable coal
4. Current production
5. Probable location of new surface mines
6. Current reclamation procedures, and State laws
7. Archaeological resources
8. Historic resources
9. Wilderness areas
10. Parks and recreational facilities
11. Wild and scenic rivers
12. Water resources - high quality streams, trout waters, polluted (acid) streams
13. Lakes and reservoirs
14. Public water supplies
15. Groundwater resources
16. Flood-prone areas
17. Wetlands
18. Critical habitats for imperiled species
19. Prime agricultural land
20. EPA responsibilities
21. Recommendations.

The conclusions in the report indicate that "EPA will have a very large number of NPDES permits to process each year, many of which will be for very small surface mines that will operate for three years or less. Consequently, the opportunity for piecemeal decision making is great". A separate environmental assessment for each mine would not only be a cumbersome job, but the overall environmental impact would not necessarily be analyzed. Figure 1 is a map of West Virginia, depicting the distribution of coal mining throughout the state by size of mines and county.

In determining the most effective program to meet Federal laws, carefully balancing available manpower and environmental benefit, an area-wide environmental assessment and impact statement is most feasible for specific geographic areas. There are strong advantages of an 'area-wide review' over a 'mine-by-mine' approach.

1. EPA can make intelligent exeditious environmental decisions with limited data. The aggregate impact of development could be more adequately assessed.
2. Strategies and plans could be developed to prevent discharges where problems abound. EPA can prioritize permit issuance by degree of pollution in a watershed.
3. Mining operators could carefully review the area-wide assessment before planning to develop in sensitive areas and prioritize development in non-sensitive areas.
4. Area-wide reviews could benefit the mine operator by expediting NPDES permit approvals where it can already be shown that environmental considerations have been made.
5. EPA will work with the Office of Surface Mining on best management practices and possible joint permits.
6. Areas unsuitable for mining can be demarcated.
7. Small mines often do not have the capability of developing proper assessments and can take advantage of the area-wide review.

Gauley and Monongahela River Basins

EPA is now reviewing the area-wide approach in two high priority river basins in West Virginia. These areas are outlined in Figure 1. River basins are an excellent geographic unit for study since partial data bases are already avialable in these watersheds. The river basins

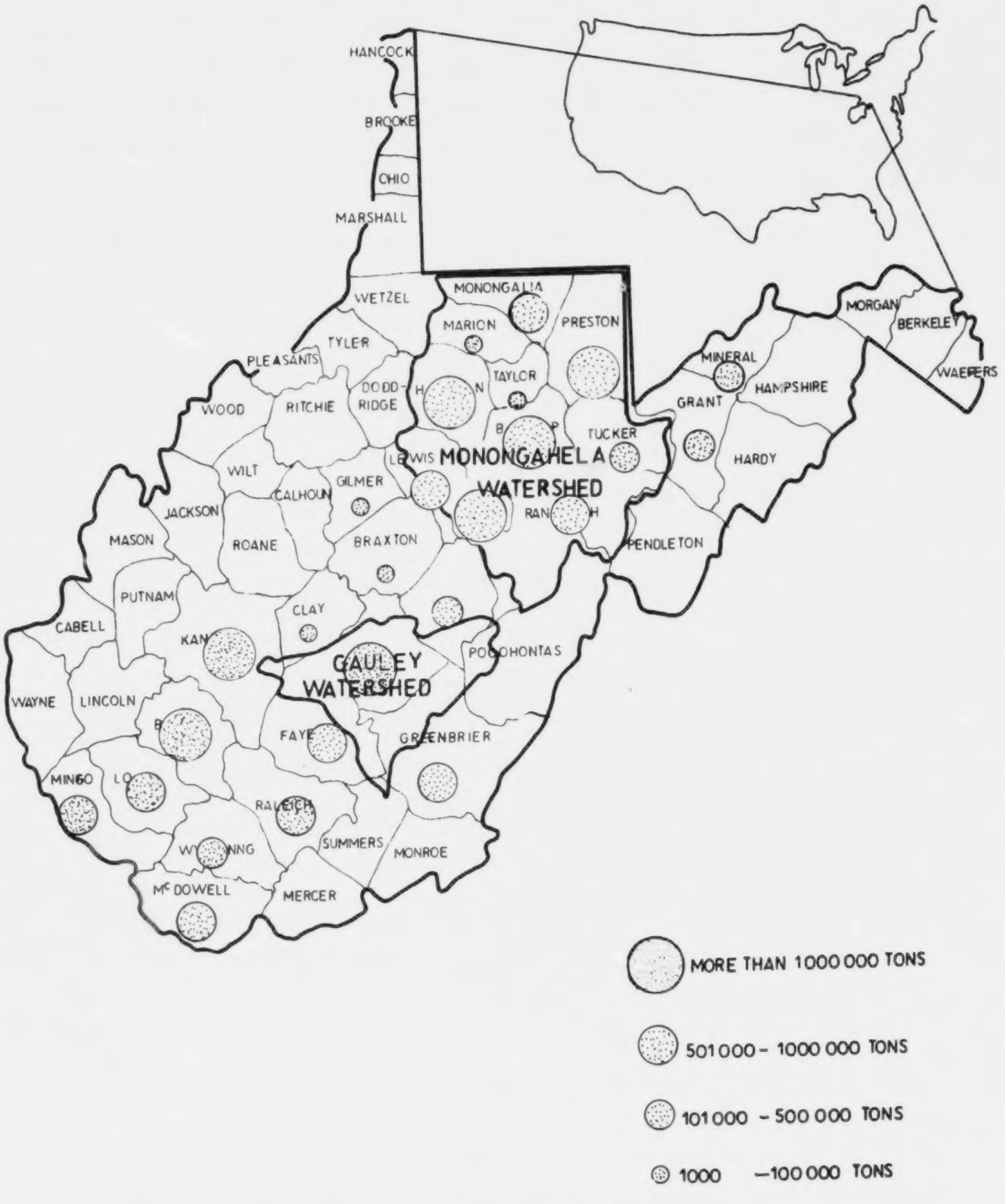
HANCOCK
BROOKE
OHIO
MARSHALL
WETZEL
TYLER
PLEASANTS
WOOD
RITCHIE
DODD-RIDGE
WILT
JACKSON
CALHOUN
GILMER
MASON
ROANE
BRAXTON
PUTNAM
CABELL
CLAY
KAN
WAYNE
LINCOLN
MINGO
LO
RALEIGH
FAYE
WY NNG
Mc DOWELL
MERCER
SUMMERS
MONROE
GREENBRIER
POCOHONTAS
GAULEY WATERSHED
MONONGALIA
MARION
PRESTON
TAYLOR
TUCKER
LEWIS
MONONGAHELA WATERSHED
RAN H
PENDLETON
MINERAL
GRANT
HAMPSHIRE
HARDY
MORGAN
BERKELEY
WAEFERS
MORE THAN 1000 000 TONS
501 000 - 1000 000 TONS
101 000 - 500 000 TONS
1000 -100 000 TONS

Fig. 1 1975 WEST VIRGINIA SURFACE MINE PRODUCTION.

are also an effective way to relate the interaction of mining in a limited area.

The Gauley River Basin is 1,400 square miles and now contains 64 active mines. Both the Gauley and Monongahela are expected to be areas of prime active mining in the future, representing 43% of the new applications in West Virginia. Our study, when completed, will map out sensitive/non-sensitive areas, potential environmental impacts, non-environmental type concerns, techniques to reduce environmental problems, monitoring sites, assimilative capacity, and other related impacts.

The area-wide study should highlight environmentally sensitive areas that could pose limitations to mining from acquifer recharge areas, sites of historic or archaeological significance, areas of soil with water table problems and other limiting characteristics such as flood plains, prime agricultural lands, air quality problem areas, or where the infrastructure (transportation systems, water supply, sewage, utilities) exceeded or were close to exceeding the capacity of that infrastructure. Mitigation measures could then be identified to eliminate the adverse impact with plans to accommodate projected growth. The mining community and citizenry of the State were informed of our process through hearings and although not informed of our conclusions at this time, have endorsed the concept.

CONCLUSION

In conclusion, because of current requirements in the U.S., it appears that an area-wide approach is one way to meet the requirements of the EPA using limited resources while considering the need for coal reserves and protection of the environment. By recognizing problem issues as early as possible in the pre-development phase, the most environmentally sound development patterns may be chosen and site specific problems minimized. In utilizing the area-wide approach, some limitations should be recognized, and new data should be continually generated allowing EPA to make informed decisions for the opening of new coal mines. This report only briefly considered the new Surface

Mining Reclamation Act. Significant effort is already underway to review application of all Environmental Laws and minimize the burden on both the administrative agencies and mine owners, while protecting the environment.

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1. Preparation of Environmental Impact Statements - New Source NPDES Permits, CFR 40, Vol. 42, No. 7, (January 11, 1977, Part 6)

2. Rebecca W. Hanmer, Policy on Application of NEPA to New Source Coal Mines: Interim Guidance, Environmental Protection Agency, Office of Federal Activities (September 1, 1977)

3. Jack McCormick Associates, Inc. (WAPORA, Inc.), Final Report on Environmental Aspects of the New Source NPDES Permit Program for the West Virginia Surface Coal Mining Industry, 1977-1980, prepared for Environmental Protection Agency (March 1977).

PRESENT AND FUTURE SURFACE COAL EXTRACTION TECHNOLOGIES IN THE UNITED STATES

by

LeRoy D. (Bud) Loy, Jr., P.E.[x/]

INTRODUCTION

It is an honor for me to present a paper to this Second Polish/ EPA Symposium. "Present and Future Coal Extraction Technologies in the United States" is a challenging topic because, as you know, there are many different types of terrain and geology in America; and threre are also many different surface mining methods.

The United States may be divided into three mining regions: 1) Western United States - including Montana, North Dakota, Colorado, Wyoming, New Mexico, and Arizona; 2) Central United States - consisting of western Kentucky, Illinois, Indiana, Ohio, Missouri, Oklahoma, Kansas, Arkansas, and Iowa; and 3) Eastern United States (Appalachia) - covering eastern Kentucky, West Virginia, Tennsessee, Virginia, Pennsylvania, Maryland, Alabama, and southeastern Ohio. Major mining technologies utilized and under development within each region vary due to the necessity of adapting to the predominant geology and topography of the area. For each mining method discussed, there is a separate captioned illustration. Most of the new mining methods now under development and described here are being accomplished by the United States Department of Energy.

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x/ LeRoy D. (Bud) Loy, Jr., P.E. Partner, Skelly and Loy Consulting Engineers.

WESTERN UNITED STATES

Present Mining Methods

Only two major types of surface mining methods are presently employed in western United States. These are: 1) Area Type Mining; and 2) Open Pit Mining.

Area Type Mining in the West is characterized by removal of one or two moderately thick coal seams (usually between 6 and 10 feet thick), with extraction activities ultimately progressing over a relatively large tract of land. The topography is usually flat or gently sloping, with an arid climate. As shown by the illustration, spoil is directly placed in adjacent previous cuts, using either shovels or draglines for excavation. Lack of substantial precipitation is the most difficult problem confronting mine operators during post-mining revegetation.

In contrast, two basic types of Open Pit Mining are employed in western United States, depending on the thickness and pitch of the coal seams to be mined. These are both shown on one illustration. Open Pit Mining of thick coal seams (up to 100 feet thick) involves removal of thin amounts of overburden in flat terrain. Shovels are the most common equipment used to remove overburden and coal into a series of benches 40 to 50 feet high. The low ratio of overburden to caol adds to reclamation difficulties associated with the arid climate.

With the second approach, Open Pit Mining removes steeply pitching seams, either single or multiple, which vary in thickness from as little as 4 feet to as much as 90 feet. This type of Open Pit Mining is performed by having the stripping operation follow the coal down-dip. One particular Open Pit Mine in western United States is characterized by a whole series of steeply pitching seams which are mined by a series of pits on each specific coal seam; that is, each seam has its own pit, and overburden is placed both above and below the seam. Direct backfilling is not feasible and bulldozers must be employed to cover the exposed pit areas prior to revegetation.

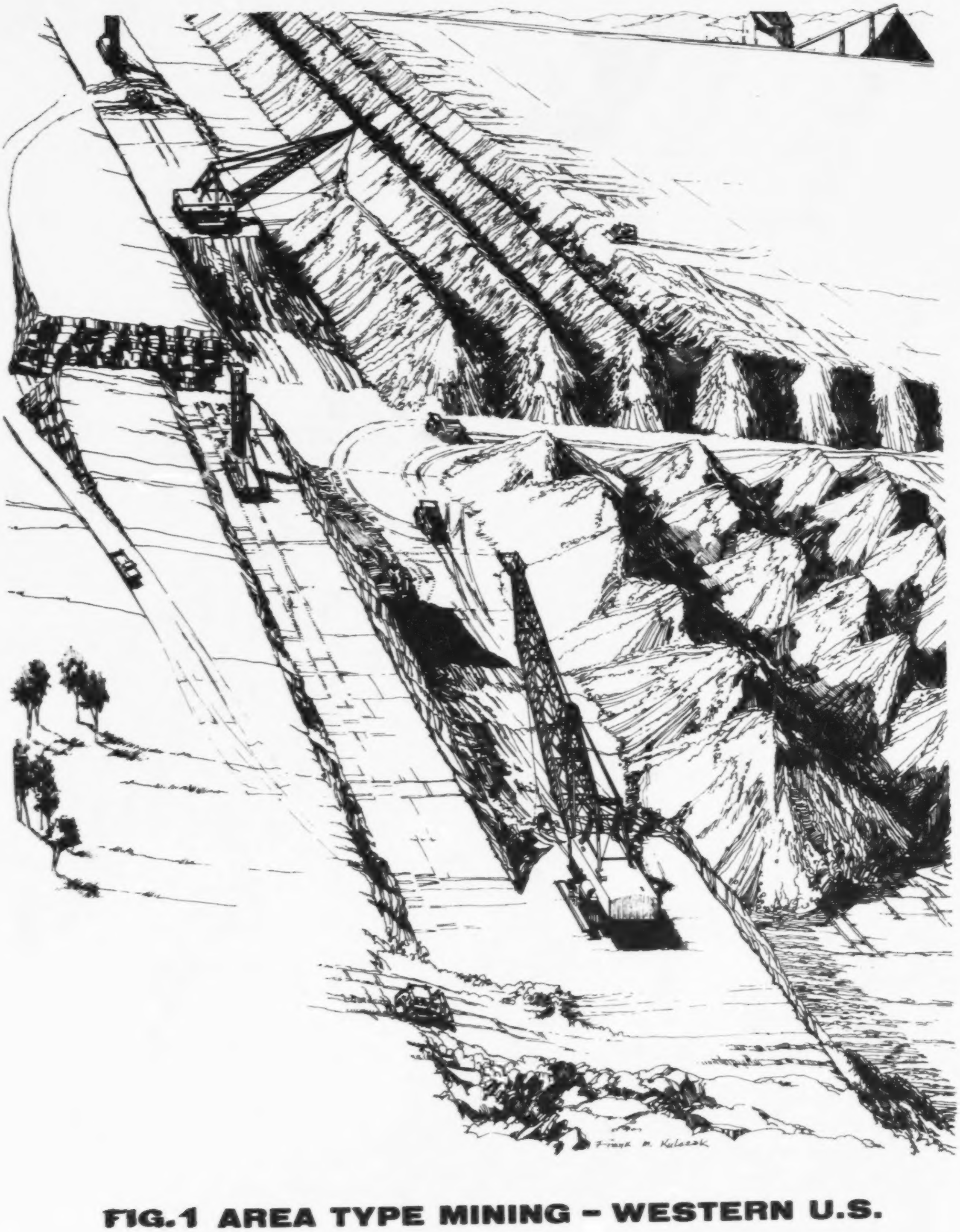
Frank M. Kulczak

FIG.1 AREA TYPE MINING – WESTERN U.S.

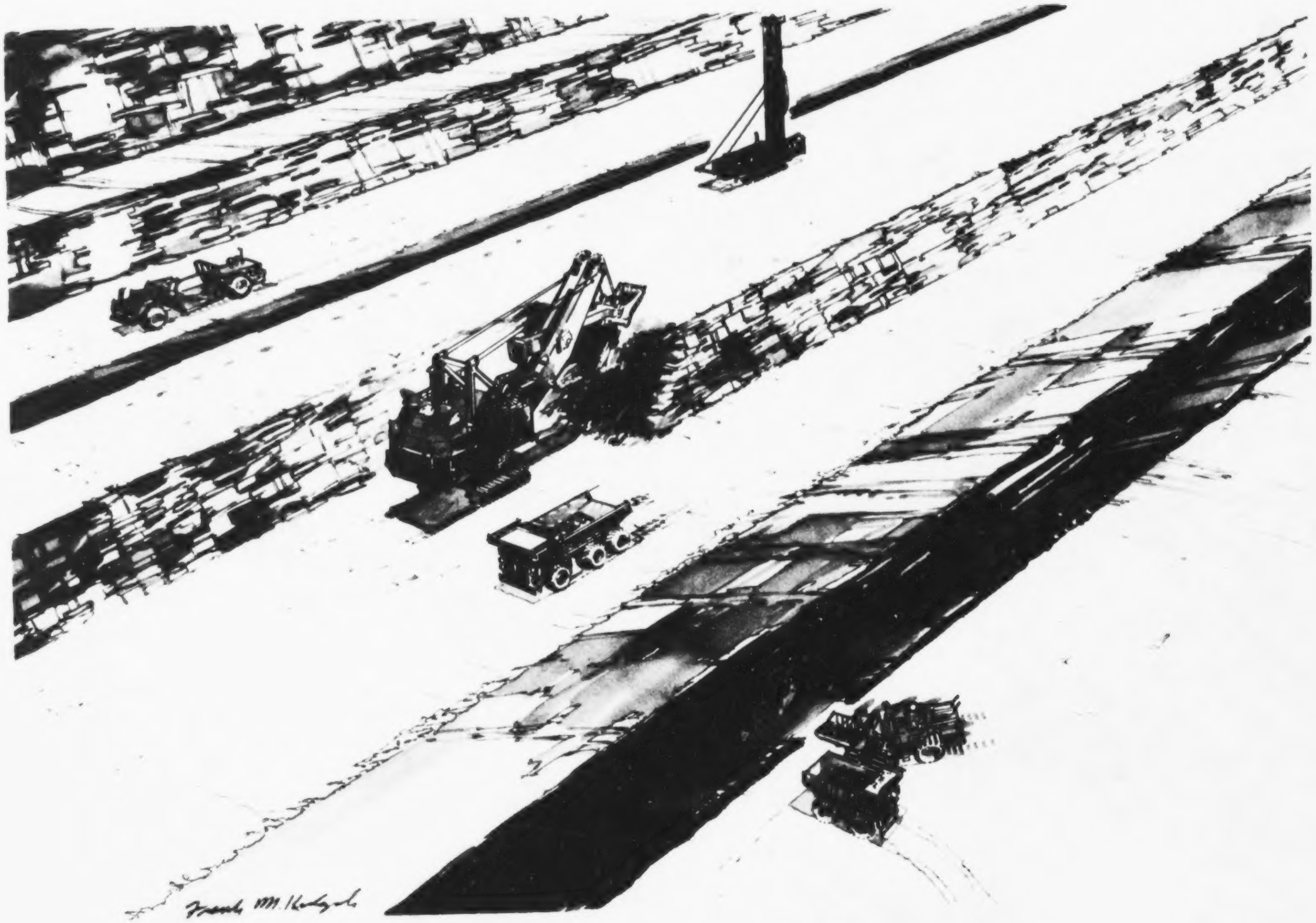

FIG.2 OPEN PIT MINING

Mining Methods Now Being Developed

Methods now being developed with regard to western Area Type surface mining include application of bucket wheel excavators and conveyors. These pieces of equipment are used to extract coal and/or overburden, in contrast with central United States where they will more than likely be used to extract and move overburden only. In part this is due to the higher ratio of overburden to coal found in most central United States mines.

A series of four Cross-Pit Conveyor Systems have been conceptualized for western Area Type Mining, and the United States Department of Energy is working to select the best of these for development.

Future mining methods related to Open Pit Mining of steeply pitching seams include applications of more mobile equipment and use of an existing highway construction machine, the Gradall. Since it can operate on steeper grades than front-end loaders or shovels, the Gradall may be useful for extracting coal from steeply pitching Western coal seams. Under a new terrace pit project, research is being conducted to find a different and more efficient extraction technology for both types of Open Pit Mining in the West.

CENTRAL UNITED STATES

Present Mining Methods

In central United States, Area Mining is used almost exclusively. The terrain varies from relatively flat to slightly rolling, and the technique is similar to western Area Mining. The climate of central United States is wetter than western United States, permitting easier reclamation, and the overburden is thicker. In rolling terrain, cropline to cropline coal mining is permitted: this slight alteration is called Modified Area Mining. Stripping shovels are used where the overburden is approximately 40 to 50 feet deep and draglines where overburden ranges as deep as 150 feet.

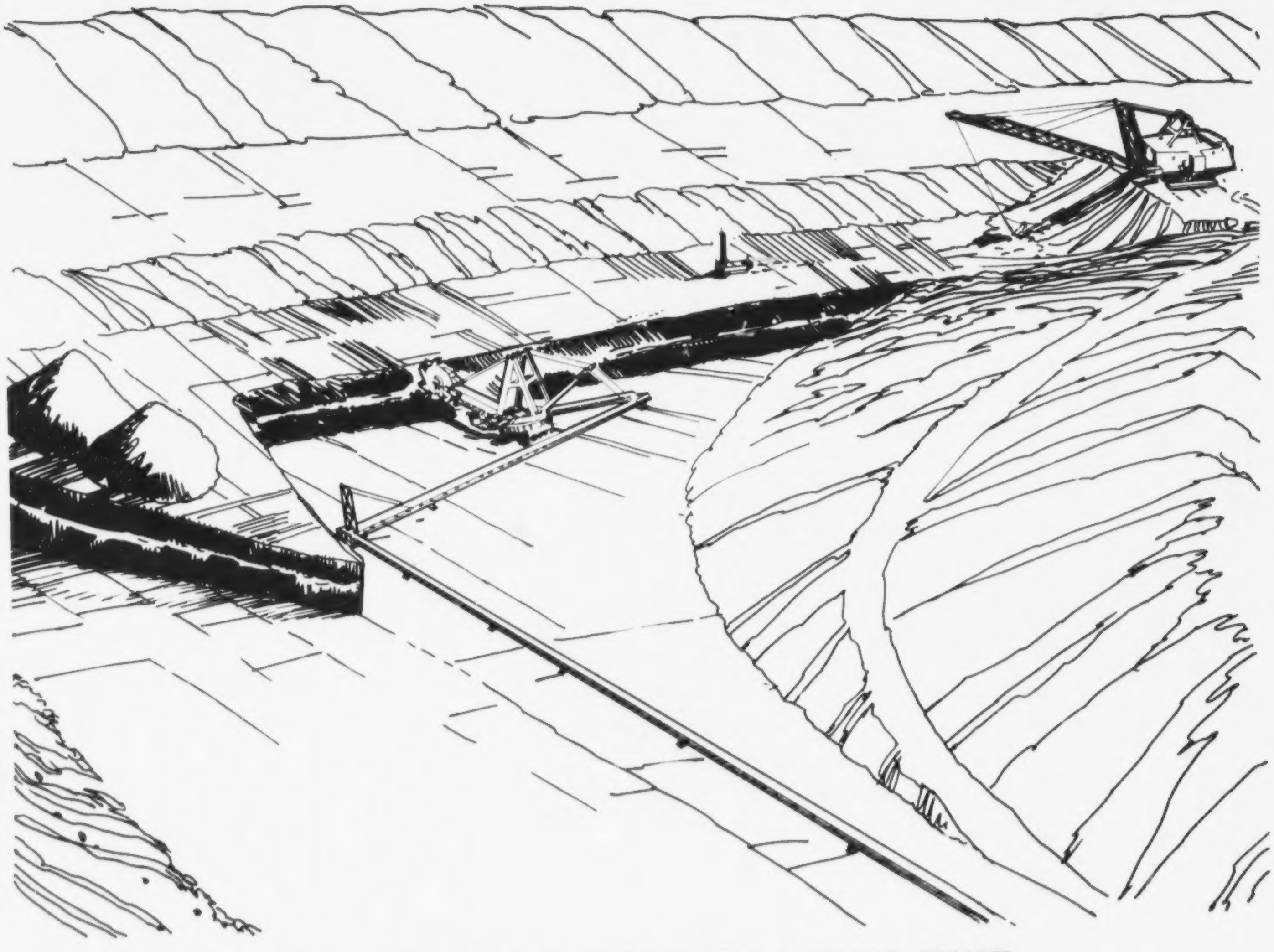

FIG. 3 COAL REMOVAL SCHEME USING BWE

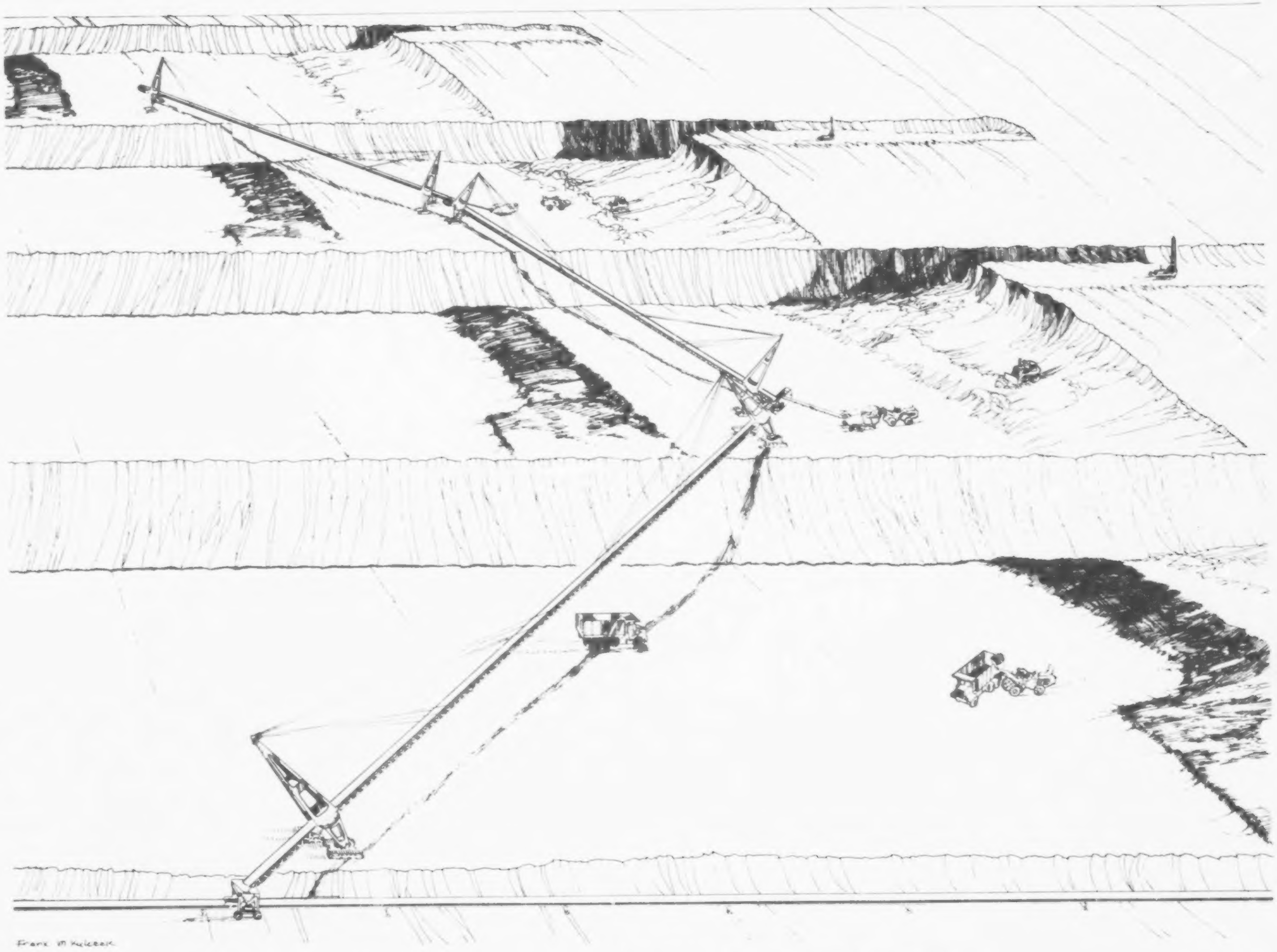
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FIG. 4 CROSS-PIT CONVEYOR SYSTEM

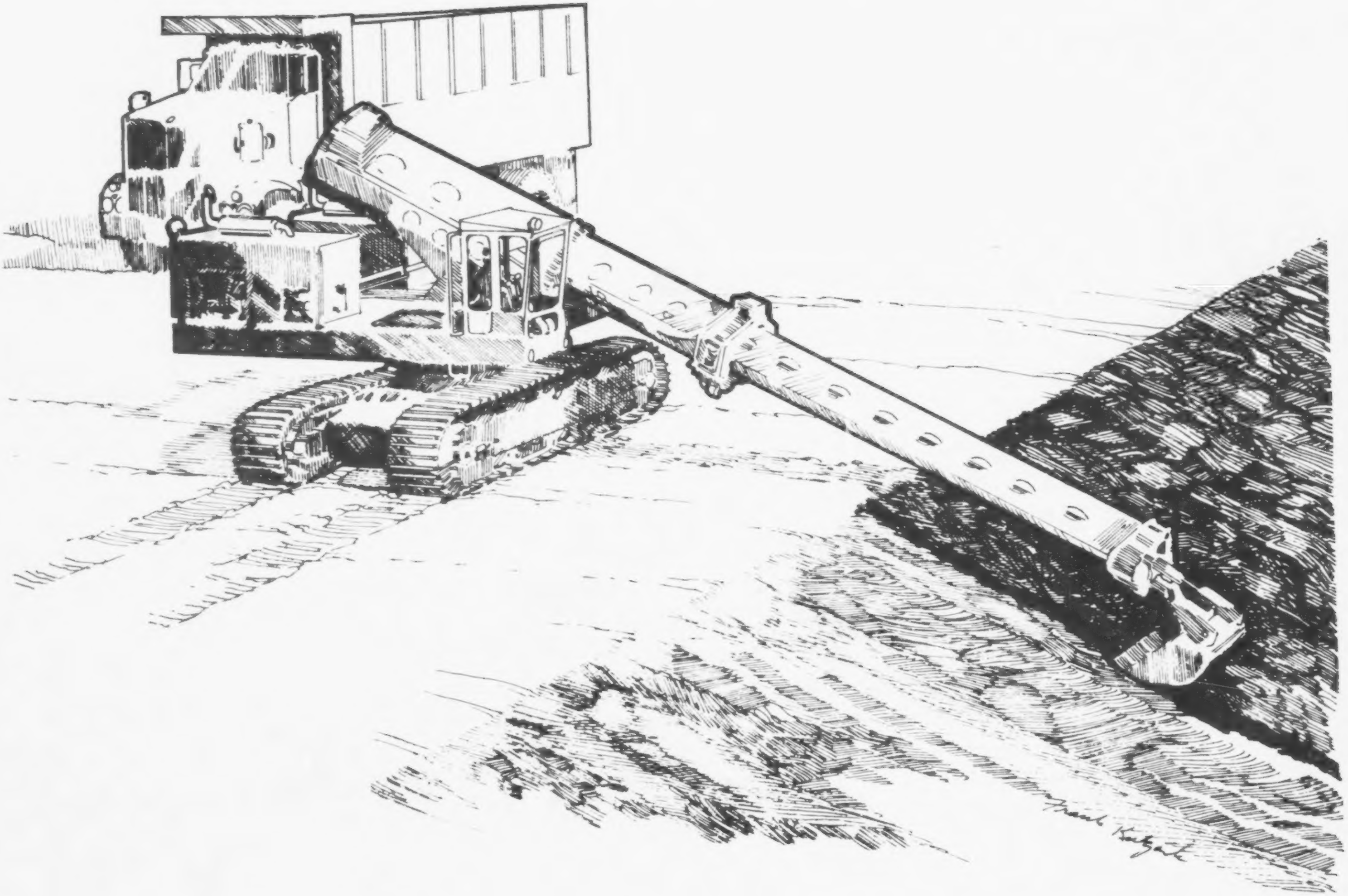

FIG. 5 GRADALL COAL REMOVAL SYSTEM

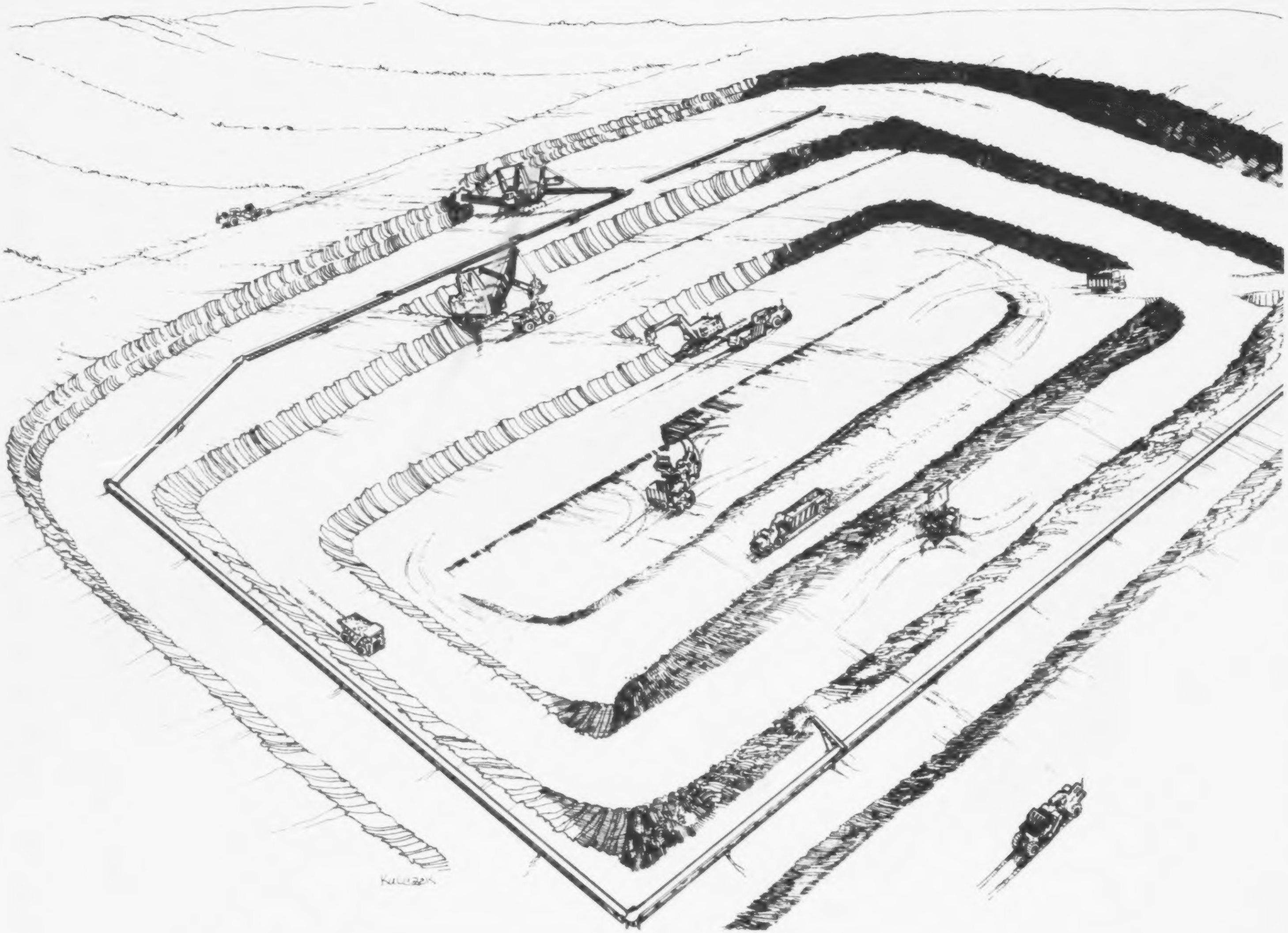

FIG. 6 TERRACE PIT MINING SYSTEM

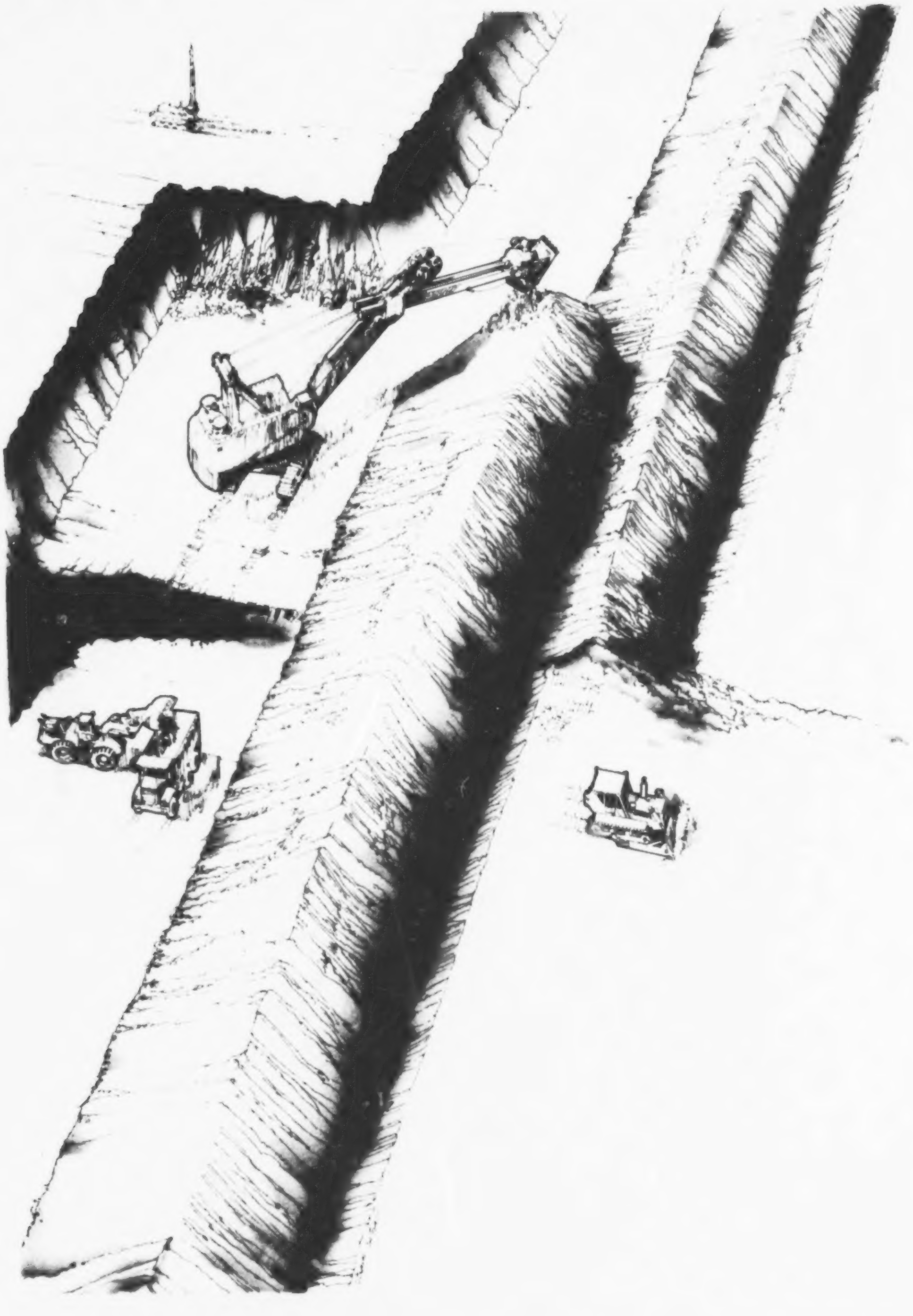

FIG. 7 MODIFIED AREA MINING - CENTRAL U.S.

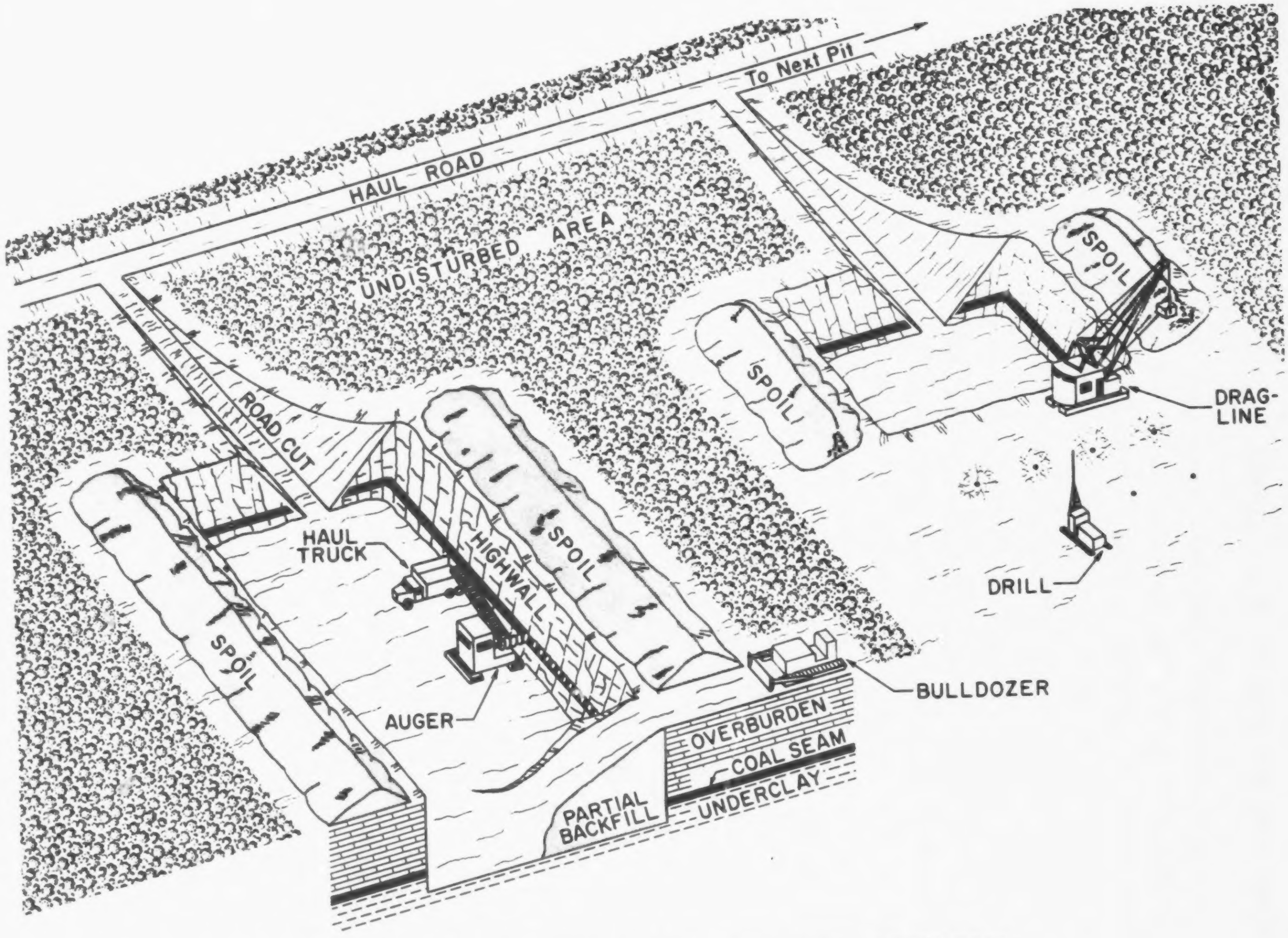
HAUL ROAD
To Next Pit
UNDISTURBED AREA
ROAD CUT
SPOIL
SPOIL
SPOIL
SPOIL
HAUL TRUCK
HIGHWALL
AUGER
PARTIAL BACKFILL
OVERBURDEN
COAL SEAM
UNDERCLAY
BULLDOZER
DRILL
DRAG-LINE

FIG. 8 TRENCH STRIP AND AUGER MINING

Mining Methods Now Being Developed

Portable conveyor units have been used in Europe for a number of years, but so far they have not been put to use in central United States stripping operations. However, their potential for application in this region is excellent. Conveyor units are described later in this paper under the topic of eastern United States.

Another new technique under development which shows promise for central United States is called Trench, Strip, and Auger Mining. This system disturbs much less land than other methods of mining. It is environmentally sound and allows recovery of deep resources with fairly thin coal seams. The method is very simple. A large trench or ditch is excavated down to the coal seam, from which the coal is then removed. Large augering machines bore into both sides of the trench previously excavated. With this method there is no problem with drainage from augered seams, because when reclamation is accomplished and the mined area backfilled, there is no place for water to go. When the trench has been excavated and augering completed on each side of the trench, the process is advanced by repeating the entire sequence over and over.

Now let's turn to eastern United States where much more complicated methods of mining exist.

EASTERN UNITED STATES (APPALACHIA)

Present Mining Methods

There are a number of different mining methods employed in Appalachia. This is principally because Appalachia has three distinct topographic areas: "flat or gently rolling terrain", which is common to Pennsylvania and Ohio.

Flat or Gently Rolling Terrain

There are two major mining methods utilized in flat or gently rolling terrain:

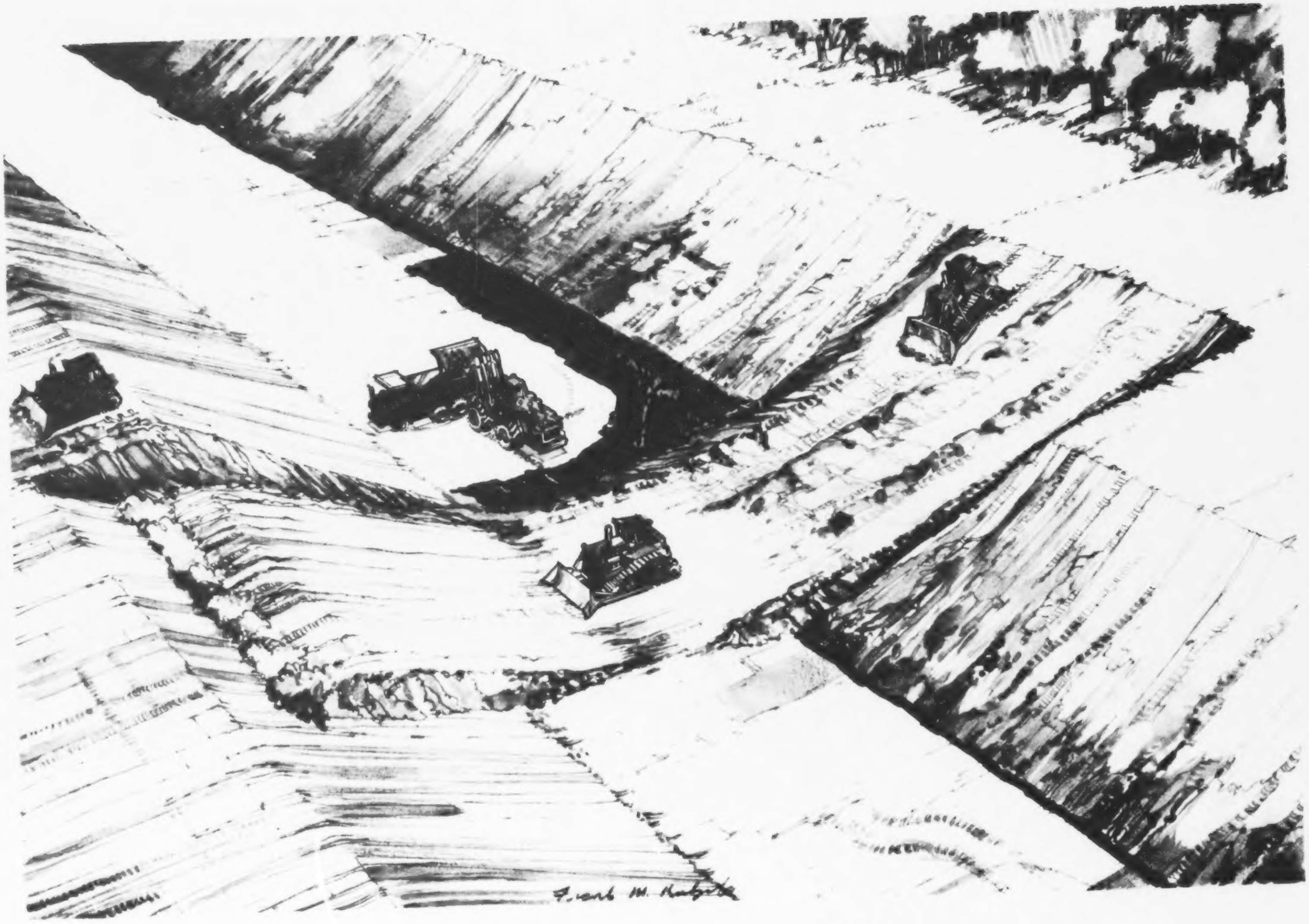

FIG. 9 BLOCK AREA MINING

Block Area Mining - - The first is called Block Area Mining, used where overburden is usually less than 70 feet deep. This mining method employed bulldozers and front-end loaders almost exclusively. Successive 70 foot wide cuts are taken, with overburden from one cut placed into the mined out cut behind it. Very thin seams can be recovered with little equipment. Flexibility and ease of mining are advantages of this type of mining operation.

Modified Area Mining -- The second method used in flat or gently rolling terrain is called Modified Area mining, which was already discussed as a major surface mining method in central United States. As the illustration shows, mining can take place from cropline to cropline, usually with 150 feet maximum overburden. One of the requirements of the new Surface Mine Law is that the land be regraded to approximate original contour. However, there are exceptions that can be made to this requirement. In this case, because Modified Area Mining is accomplished in rather flat or gently rolling terrain, return to approximate original contour is fairly easy to accomplish.

Hilly or Moderately Rolling Terrain -- Where "hilly or moderately rolling terrain" is present, primarily in northern West Virginia, Pennsylvania and western Kentucky, two major techniques are employed.

Modified Block Cut -- One is called Modified Block Cut, which is a contour method of mining. All spoil is moved laterally along the bench, mainly by direct placement, with dozer/loaders. The Modified Block Cut Method is primarily applied in Pennsylvania. The advantage here is that there is no spoil placed downslope following the initial cut removal and, in fact, the new surface mine law prohibits placement of spoil downslope. This ensures that environmental disturbances are restricted to the actual area being mined. The mined area also must be returned to approximate original contour as required by the new law.

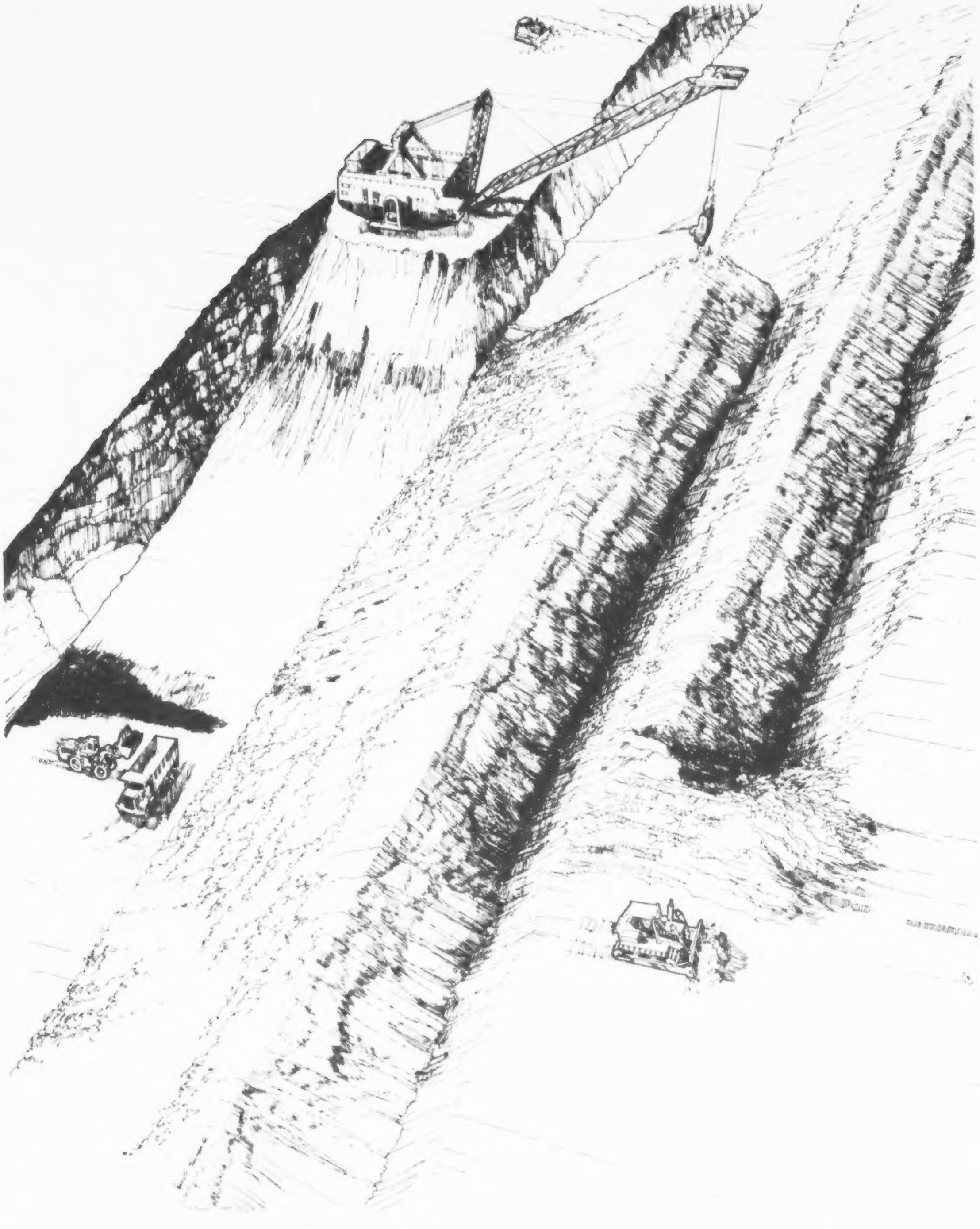

FIG. 10 MODIFIED AREA MINING - EASTERN U.S.

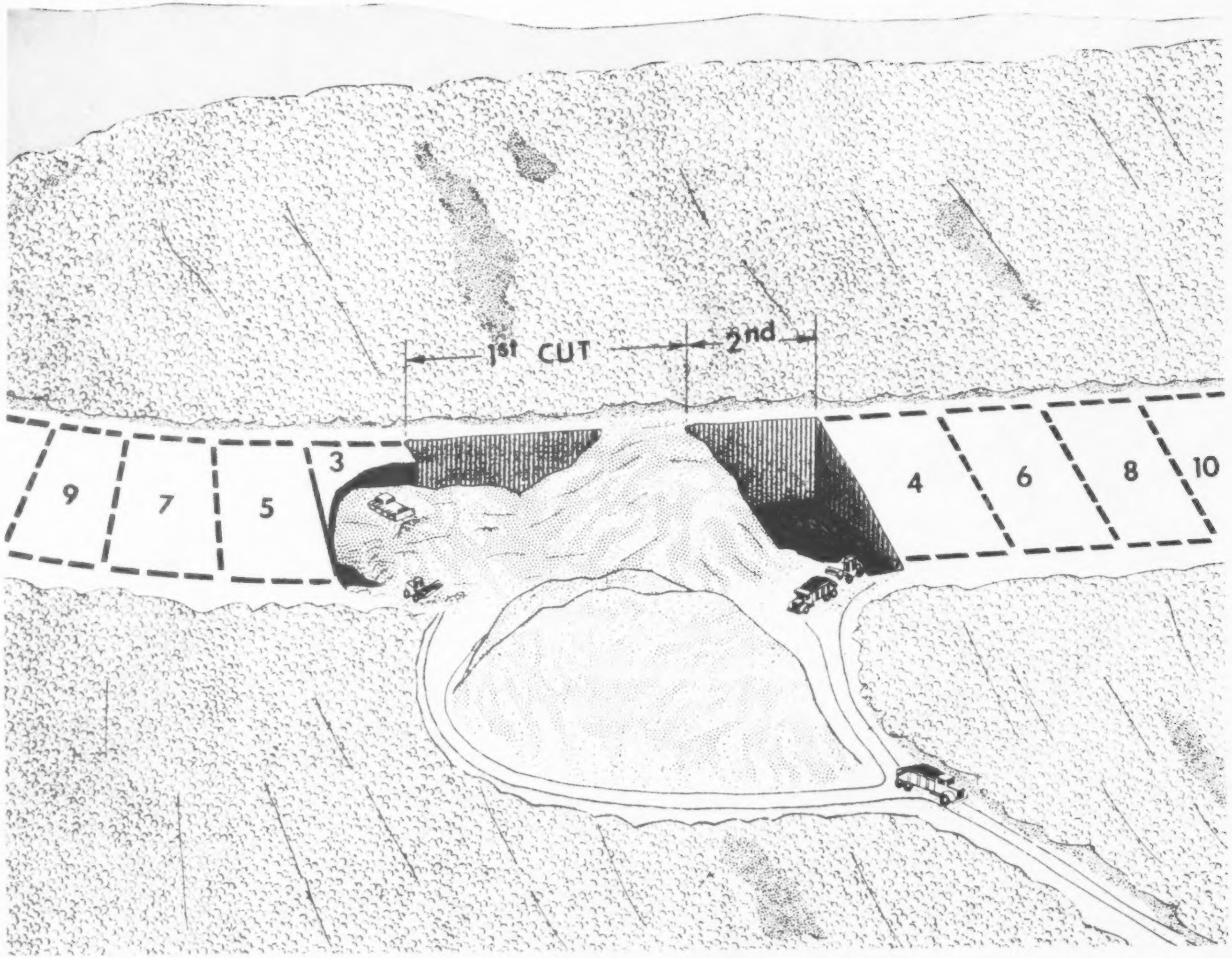
1st CUT
2nd
3
9
7
5
4
6
8
10

FIG. 11 MODIFIED BLOCK CUT MINING

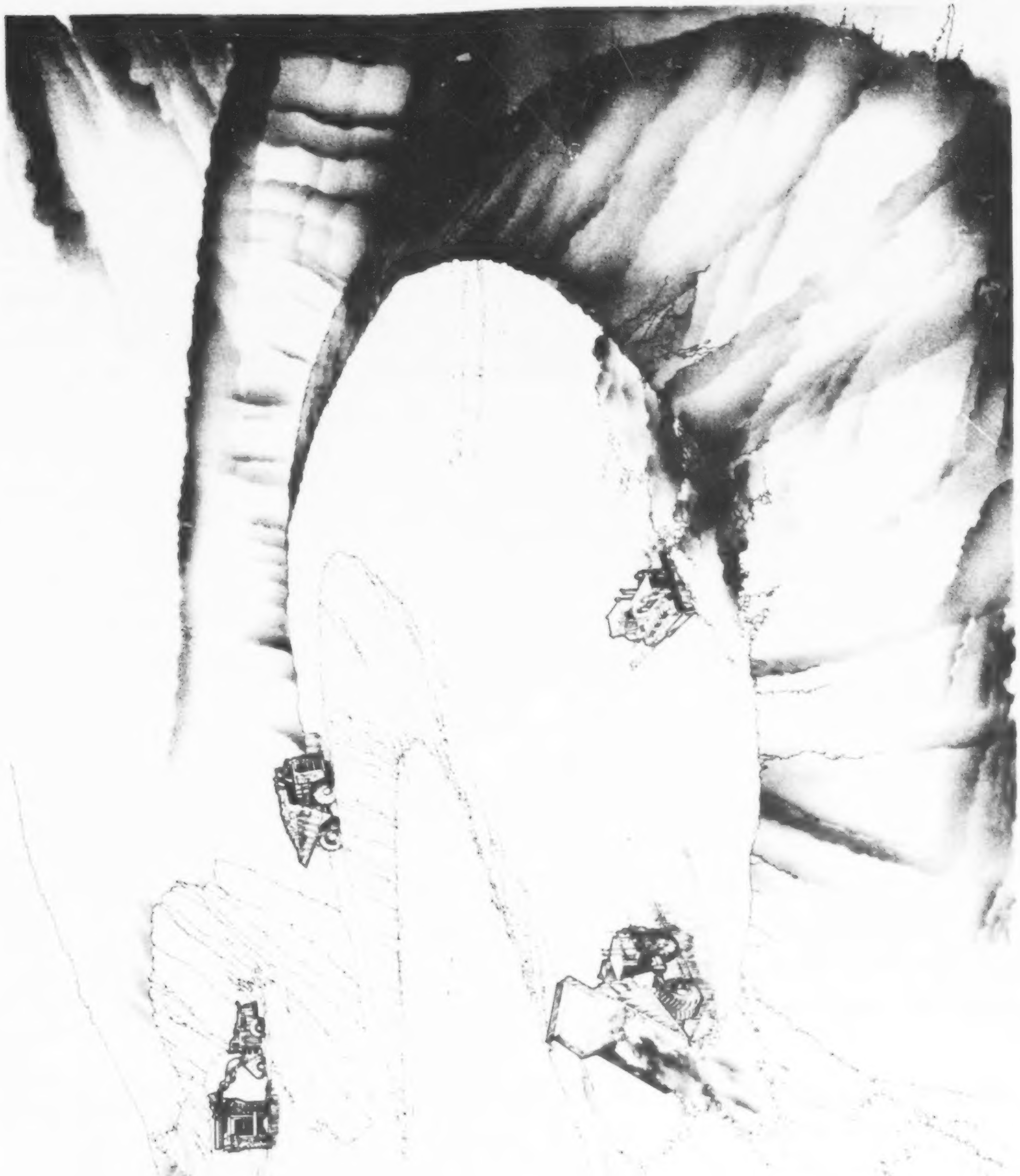

FIG. 12 CONTOUR HAULBACK MINING

Haulback -- Haulback is also a contour mining method, and is cometimes called Controlled Placement or Lateral Movement Mining. Trucks move the material along the bench, requiring longer open highwalls than with dozer/loader Modified Block Cut operations. A valley fill or head-of-hollow fill or old mine bench is required for placement of waste material from the first cut, because no material is allowed downslope. Overburden is transported by trucks after its excavation by bulldozers, front-end loaders, shovels, hydraulic shovels, or even an occasional dragline. As with Modified Block Cut Mining, this method is environmentally sound. Reclamation is fairly easy to accomplish, and the approximate original contour can be returned after mining is completed.

Mountainous or Very Steep Terrain

In "mountainous or very steep terrain" such as is common to eastern Kentucky, southern West Virginia, and Tennessee, there are several methods used:

Haulback -- Use of Haulback in mountainous or very steep terrain is much more difficult. The new law requiring return to approximate original contour means that no highwall can be left exposed. However, when the terrain is steep, it is very difficult to completely backfill the highwall. Less than half of the steep terrain areas are now being mined with the Haulback technique; most are being mines with the mountaintop removal method.

Mountaintop Removal -- Mountaintop Removal is a technique where, as the name implies, the entire top of the mountain is taken away, permitting total resource recovery of both single and multiple seams. This type of mining operation is allowed under the new strip mine law, and with good premine and future land use planning, it is a desirable and environmentally sound method. Previously, mine operators took contour cuts, ringing the mountain and leaving an "applecore", or unmined center section, because it was not economical to remove the

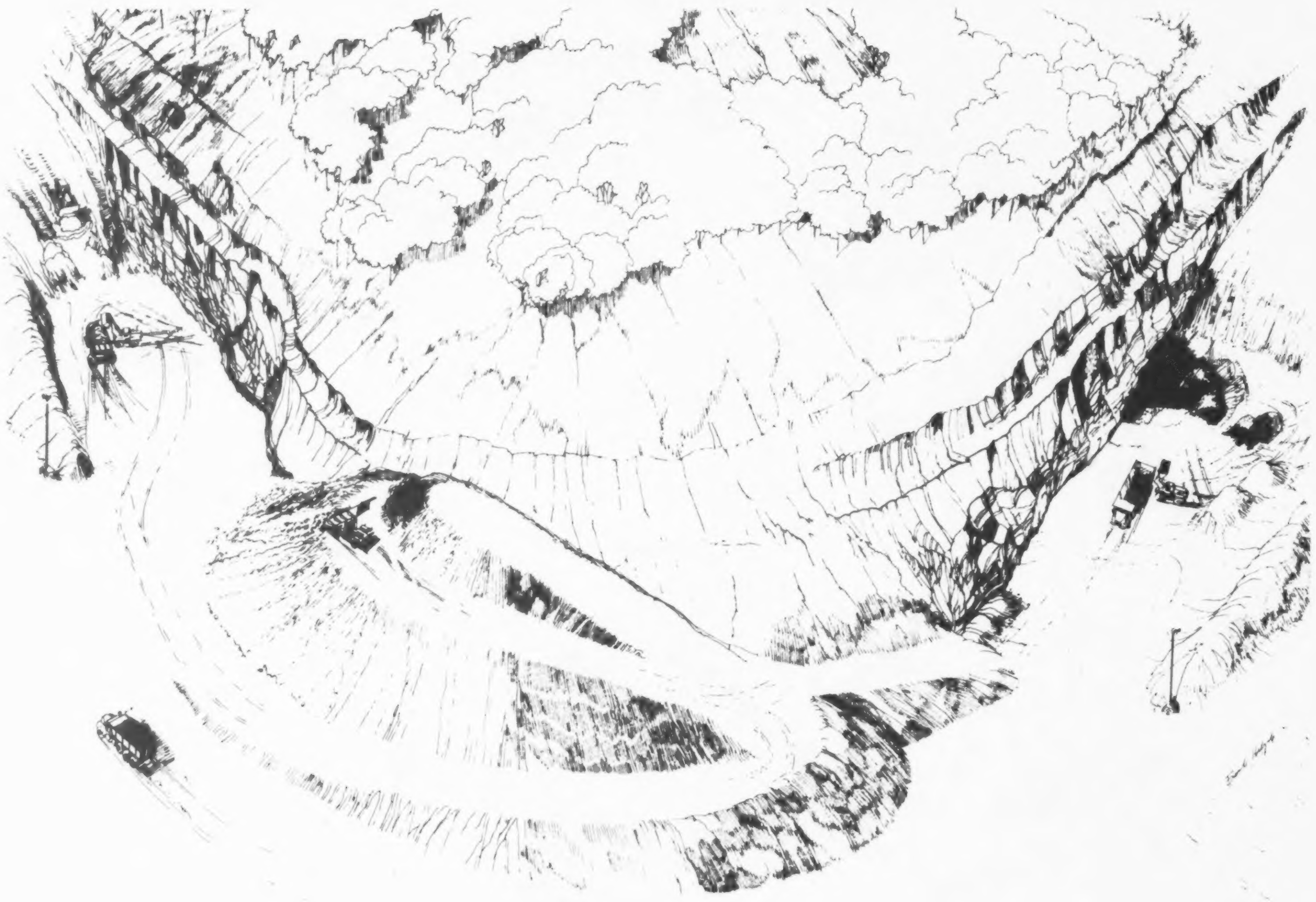

FIG. 13 CONTOUR HAULBACK MINING - STEEP TERRAIN

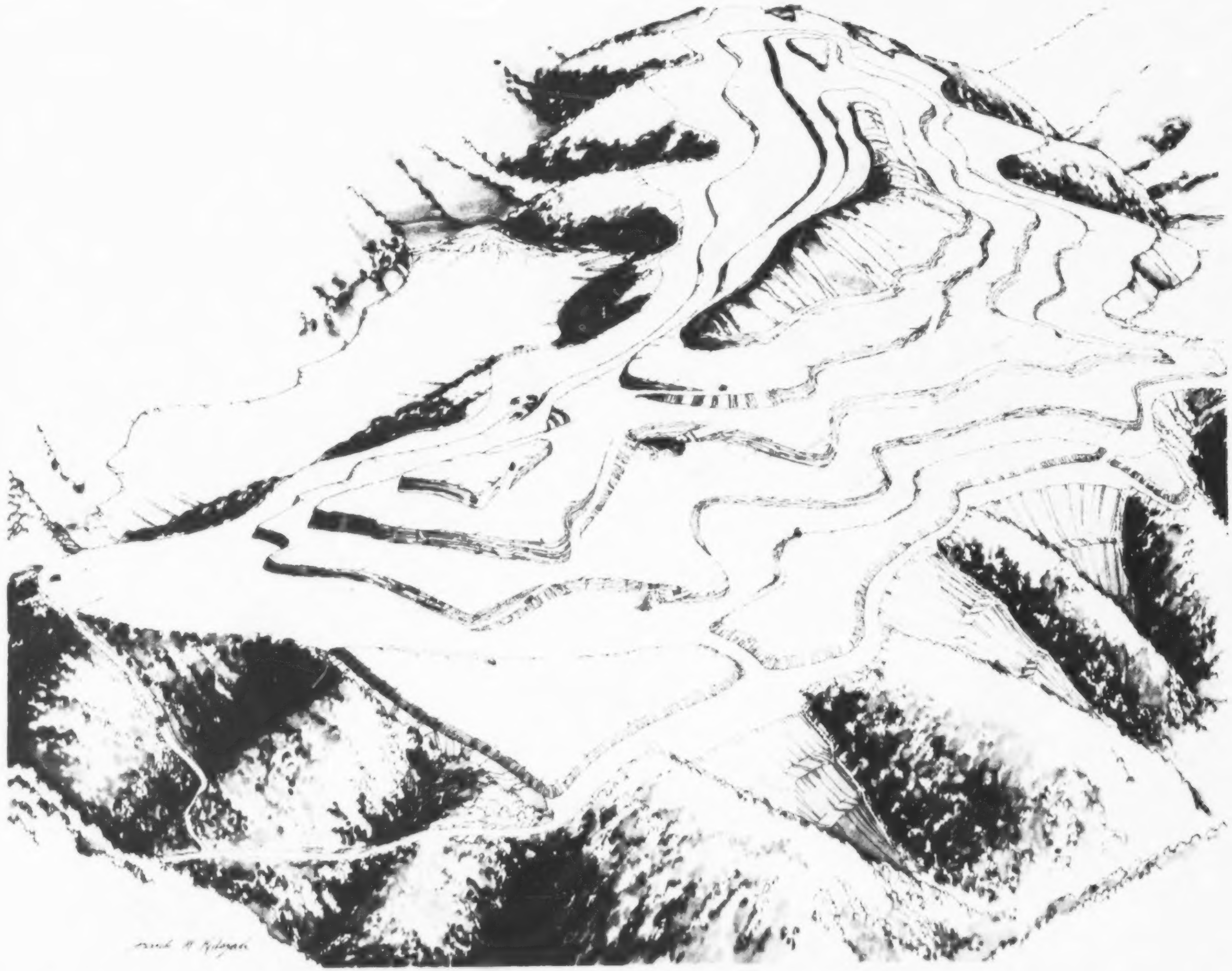

FIG. 14 MOUNTAINTOP REMOVAL SCHEME

overburden in the thicker center. Leaving these "applecores" is not permitted under the new law. Cross-ridge mining, discussed in the next section of this paper, is being developed in order to make removal of the entire top of the mountain economical. As with Haulback Mining, in Mountaintop Removal operations, valley fills or old strip mining benches must be used to deposit the first cut of waste overburden removed from the mountain.

Mining methods now being developed

The most promising mining methods now being developed for Appalachia involve use of Portable or Mobile Conveyor Systems. These Portable Conveyor Systems are being developed for all three Appalachian terrains: "flat or gently rolling"; hilly or moderately rolling"; and "mountainous or very steep" terrain.

Portable Conveyor Systems -- Taking them one at a time, we'll start with the "gently rolling terrain" where Modified Area Mining is used.

Modified Area Mining -- The artist's sketch shows how conveyors can be used to help accomplish Modified Area Mining. Modified Area Mining has traditionally required double handling of overburden material where draglines have been working beyond their boom capacity. When draglines reach the limit of their boom length, they must work on an extended bench (create a bench for themselves), and then remove it, thus handling material twice.

Using conveyors, double handling can be eliminated and spoil placement controlled. Conveyors facilitate topsoil replacement and final vegetation, including seeding, liming, and mulching. All of these materials can be added to the conveyor at the appropriate time as the topsoil passes by. This type of mining, as mentioned earlier, is also being developed for application to central United States Area and Modified Area Mining Methods.

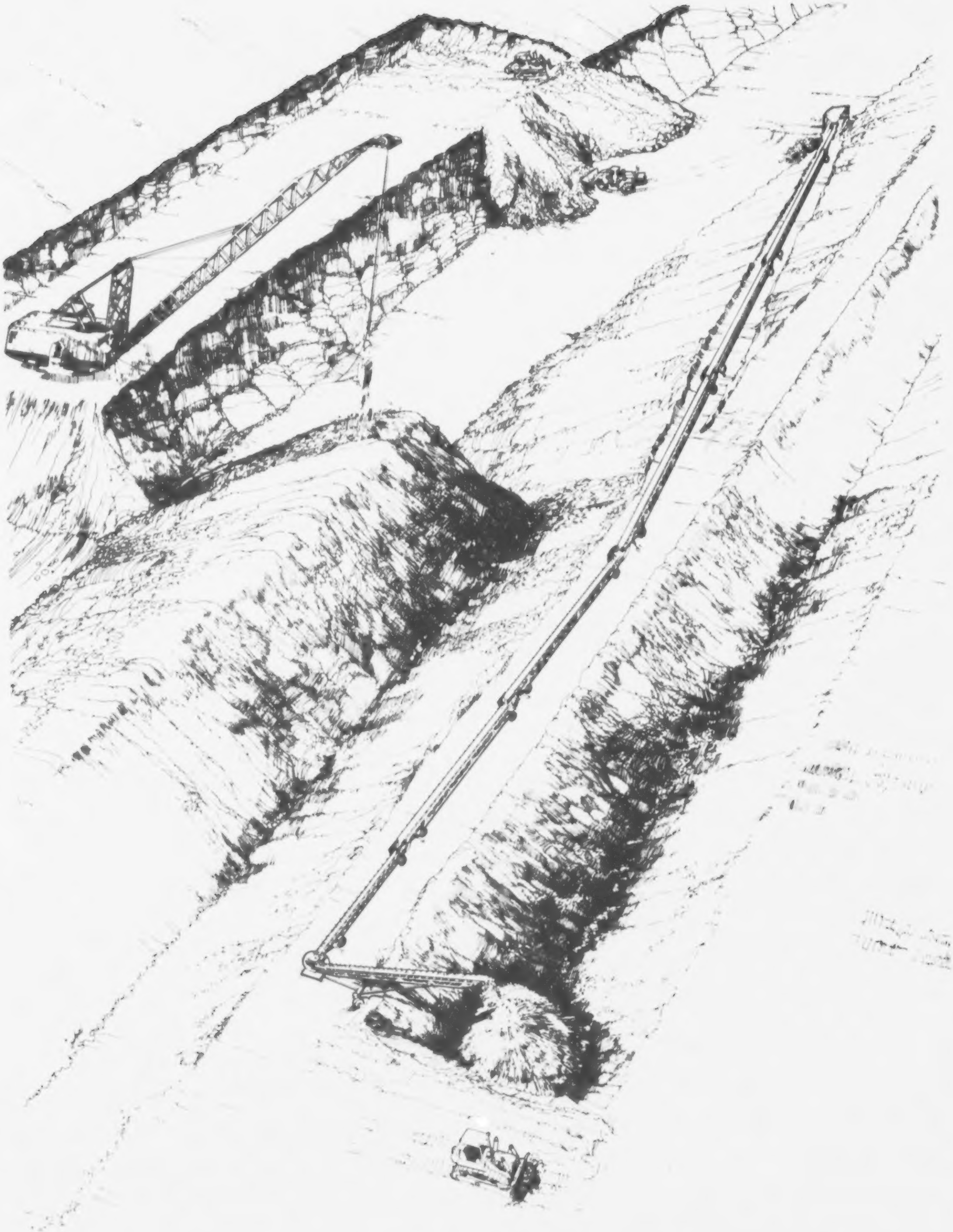

FIG. 15 MODIFIED AREA MINING WITH CONVEYORS

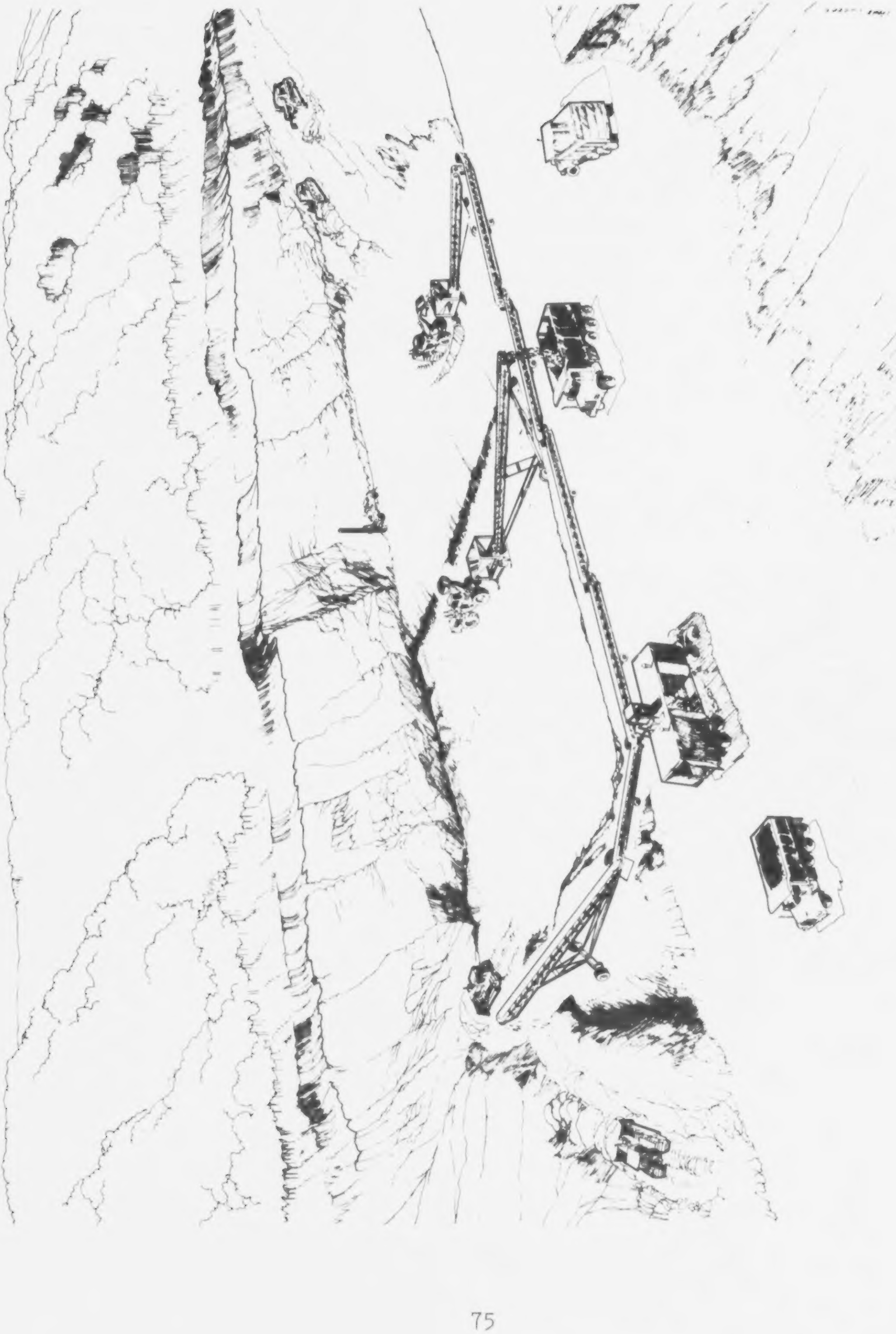

FIG. 16 CONVEYORS CONTOUR HAULBACK MINING

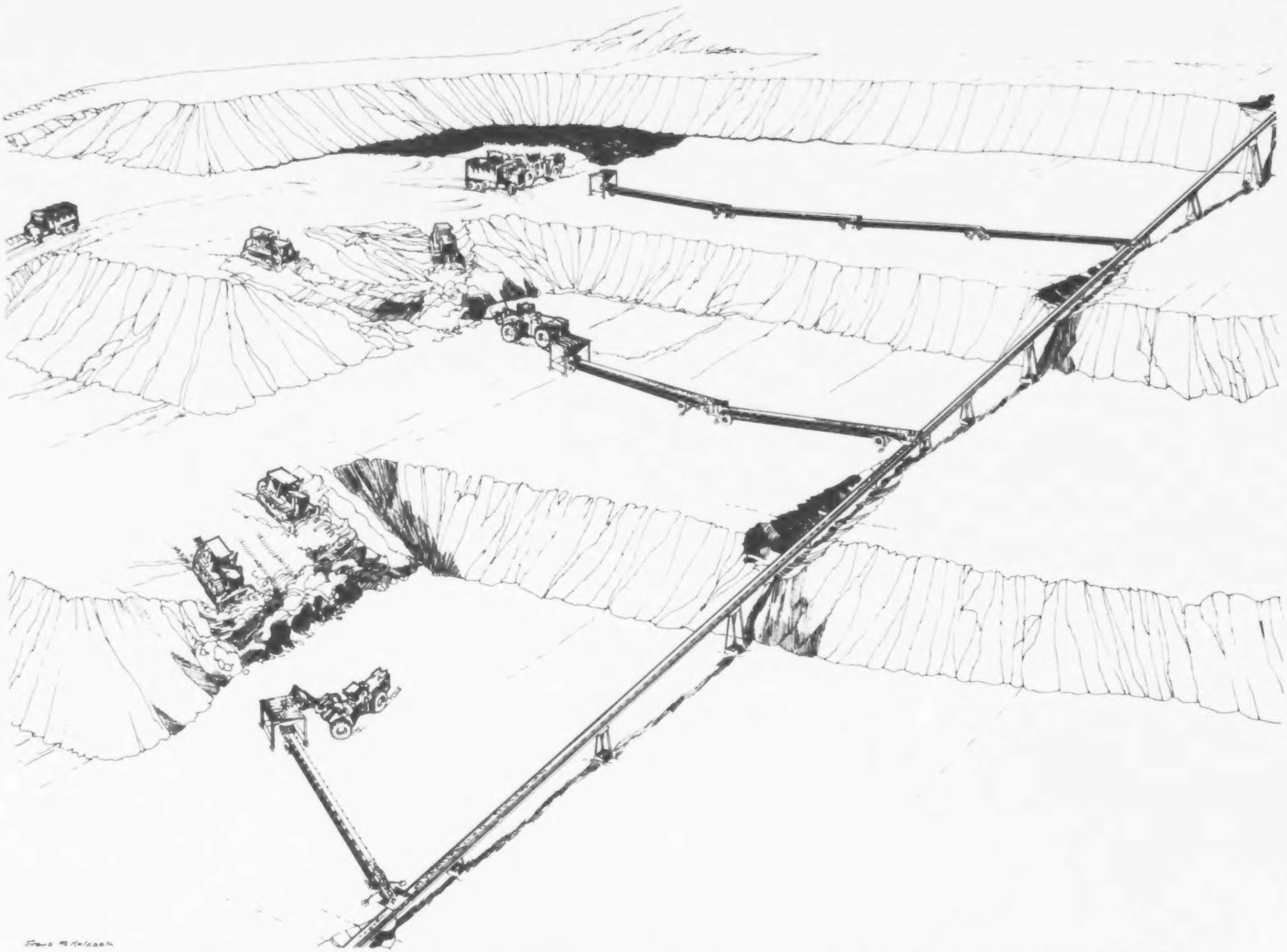

FIG. 17 CONVEYOR MOUNTAINTOP REMOVAL SCHEME

Haulback -- Haulback is also being developed with Portable Conveyor Systems. This is primarily practiced in "moderately rolling to slightly steep" terrains. As shown here, the conveyor units are placed along the low wall, or outbound side, of the haulback operation. Excavated overburden is loaded on the conveyor units to be carried along the low wall and deposited at the reclamation end of the project. Since this restricts haulage of the coal in and out of the pit, an elevated type conveyor unit must be used to bring the coal up over the low wall conveyors and into the waiting haul trucks.

Use of conveyors provides many environmental benefits, including segregation of overburden - that is, the overburden can be placed back in the same sequence in which it was excavated. Since materials handling is continuous, reclamation can be accomplished quickly. Soil supplements, including lime, seed, fertilizer, and even mulch can be added to the topsoil as it moves along the belt. Use of conveyor units offers many safety benefits, since the truck congestion on short narrow benches associated with Haulback operations is eliminated.

Mountaintop Removal -- The next category is Mountaintop Removal in very steep terrain. Continuous material handling afforded by mobile conveyors allows greater safety, facilitates valley fill construction, and enhances the environment if preplanning for future land use is done well. Aesthetic reclamation is a necessity in this type of operation; otherwise the final result is flat mountaintops which are unusable and undesirable from an aesthetic and environmental standpoint.

Cross-Ridge Mining

Because of the new law prohibiting exposed highwalls to be left after mining, a new technique of removing the entire top of a mountain is under development. The Cross-Ridge technique requires mining perpendicular to the long axis of the mountaintop. Since approximately two-thirds of the Appalachian landform consists of hilly and mountainous areas, this method has wide potential application in the eastern United States.

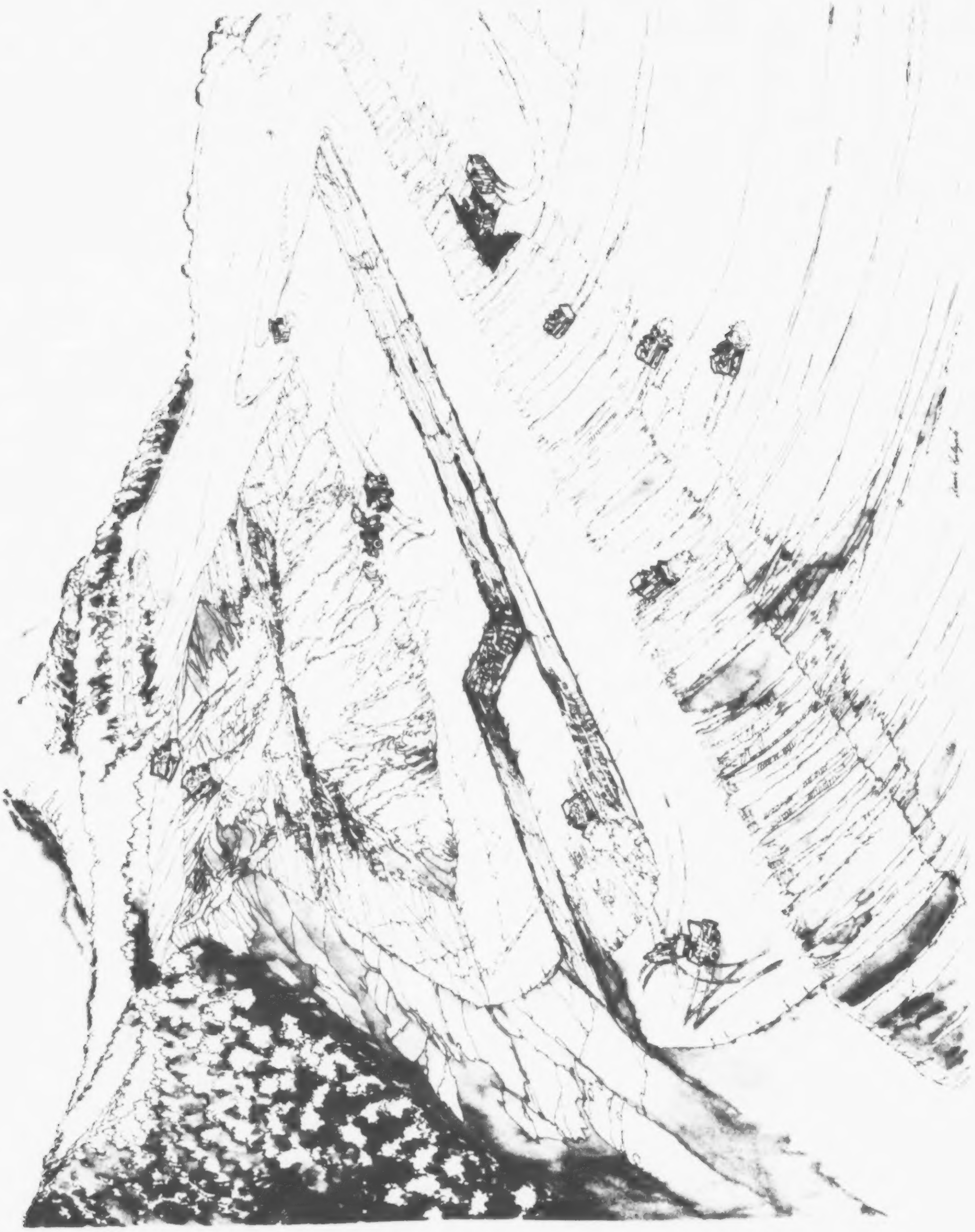

FIG.18 CROSS-RIDGE MINING

The equipment used is flexible and mobile. Most operations use dozers with front-end loaders, but hydraulic shovels and power shovels are becoming popular. By extracting the accessible outcrop coal and the thicker overburden at the center of the mountain simultaneously, the operator's cash flow is equalized over the life of the mine. Complexities of Cross-Ridge Mining require good planning of the entire operation from beginning to end.

One of the major advantages of Cross-Ridge from an environmental standpoint is that, by backstacking waste overburden on the area that has been previously mined, valley fills for overburden disposal disturb only one-fifth of the land that is normally disturbed by a Contour Mountaintop Removal operation. This is because Contour Mountaintop Removal requires placing nearly all of the waste overburden material in valley fills, whereas Cross-Ridge Mining requires use of a valley fill for only the first cut of waste overburden. This technology has been developed and is being demonstrated by the United States Department of Energy on several Appalachian sites with typical topography, facility typical geology, and conventional equipment usage.

Anthracite Open Pit Mining

There are large anthracite deposits in eastern Pennsylvania which have traditionally been mined by relatively small surface open pit operations. Some have been large enough to employ draglines. Because of the steeply pitching seams prevalent in this region, large scale open pits have excellent potential for application to anthracite coal mining. While they are used for iron ore and other hard rock mining in western United States, they have not yet been applied to anthracite mining.

Dimensions of anthracite open pits are expected to be 800 feet deep, one-half mile wide, and three-quarters mile long. As excavation takes place in the advancing face of the mine and reclamation takes place behind, the pit will "move" across the landscape. This is an environmentally sound method because reclamation follows mining right away. In eastern Pennsylvania, there are many old unreclaimed surface

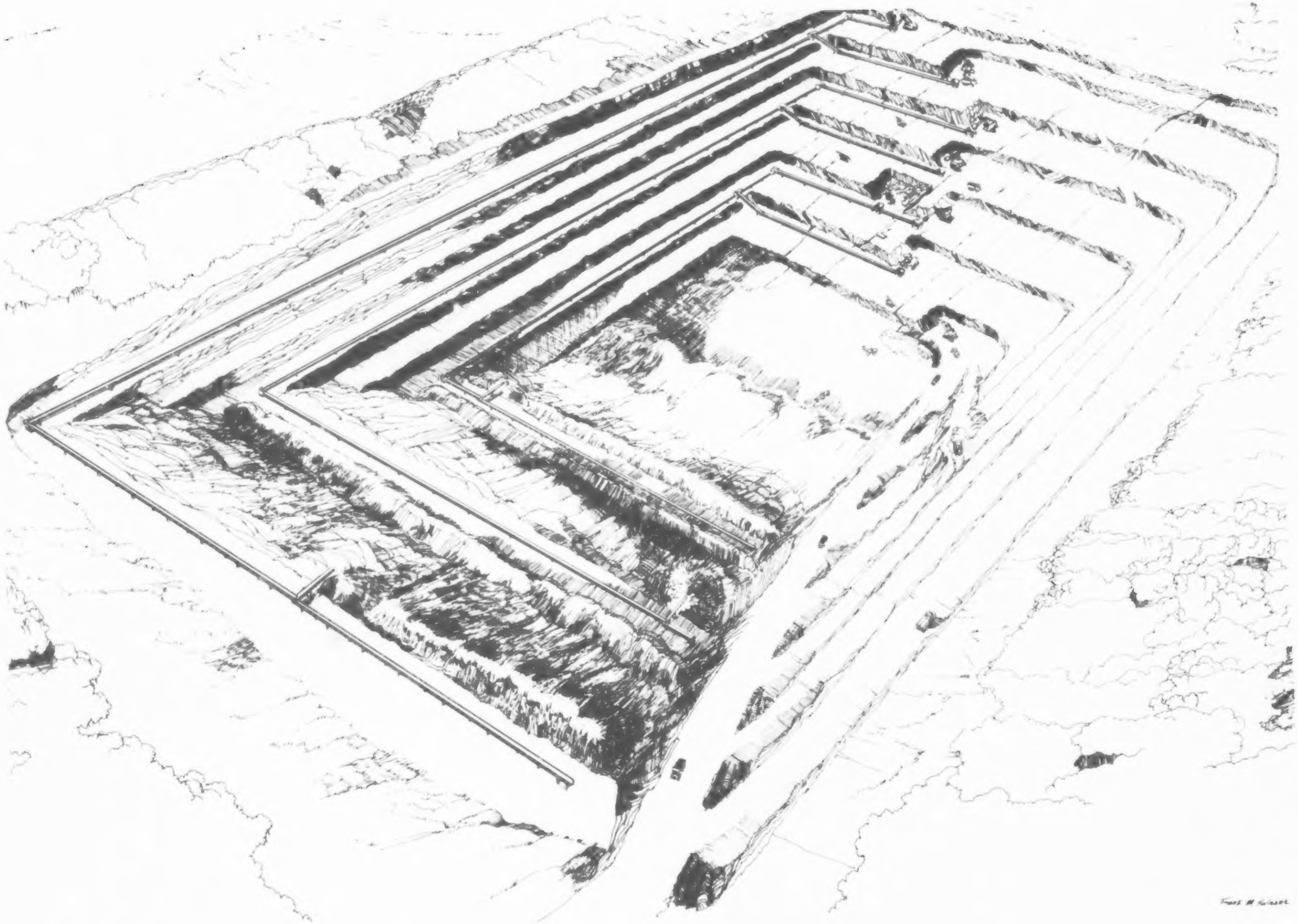

FIG.19 ANTHRACITE OPEN PIT MINING

mine scars which would be removed and reclaimed as part of the mining operation. This method would also help eliminate deep mine subsidence problems as abandoned underground mines are removed by the large open pit.

SURFACE MINING OF LIGNITE WITH BELT CONVEYORS AND ITS ENVIRONMENTAL ADVANTAGES

by

Henryk Turała x/
Władysław Wysocki

INTRODUCTION

The belt conveyor transport with its many advantages is now replacing rail haulage in surface mines in Europe. With the use of belt conveyor transport there are no limitations regarding the depths of open pits, the thickness of overburden or magnitude of uncovered sources of useful mineral. Also there are no limitations in respect to the lithological composition of the excavated rocks except rocks of great hardness, for the working and transport of which multi bucket excavators or the belt conveyors are not used. The advantage of belt conveyors is possibility of transportation over inclines up to 18° angle and so helps to shorten transport routes, thus reduces the volumes of development cuts, and allows to reach great depths of excavation or great heights of spoil disposals. Owing to the possibility of effecting changes in the length of working fronts, the technological system with belt conveyor transportation makes possible deposit development with volumes of opening cut 2 to 4 times smaller than with circumferential rail or truck transportation (with the same thickness of overburden).

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x/ Dr. Henryk Turała - Director of Poltegor, Dr. Władysław Wysocki - Principal Investigator, POLTEGOR, Rosenbergów 25, Wrocław.

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The economic range of the belt transportation depends on the size of assignment. For the task of transporting 10-30 mil. m^3 of material annually this range comes to 2-5 km. Optimum length of the multi bucket excavators working front, with the method of output transportation under discussion comes to 1.0 - 2.5 km. The system of shifting a working face may be fan-wise or parallel. To diminish the frequency of shifting the conveyors the parallel shifting of faces is desirable. The use of conveyors allows initial desintegration of output directly at the faces or on the exploitation level and ensures a continuous flow of out put.

Attention is also draw to the fact that with rocky raw material deposits the amount of overburden removal per ton of extracted raw material amounts to 0.13 m^3 in Poland, while in the exploitation of lignite this rate exceeds the 3 m^3 value. It means that, with the growing production of lignite, and the constantly diminut of the above mentioned rate, the displaced overburden masses are ever increasing (e.g. the 110 million m^3 annually of overburden from the Bełchatów mine. The scope of increasing mining operations continuously causes transformations of natural environment, as yet unencountered, manifested mainly in deformations of earth surface, in changes of water conditions in the vicinity of workings and disposals, and in the indirect impact on mines, as well as in the economic utilization of the terrains.

The main parameters affecting environment transformation in the course of surface mining operations are:

- the area of open pits up to 60 km^2
- relative depth of excavations up to 350 m
- relative height of external spoil disposals up to 250 m
- volume of external disposals above 900 mil. m^3
- the extent of depression cone more than 20 km (in an area more than 1200 km^2)
- output per excavator amounting to 33 mil. m^3 per year.

The intensity of influence as exerted by mining operations (characterized by the above parameters) warrants the recognition of a mined terrain as an industrial area. Economic potential and areal layout of such a region depends not only on the extent of mining and power engineering investments but also on the direction and fixed dates of other investment plans, (connected with the development of the region) undertaken.

The restoration of environment and the economic utilization of post-industrial terrains requires, among other things, reclamation treatments, comprising first of all:

- the profiling of crown tops and slopes of disposals and excavations,
- reconstitution of soils on the surfaces of disposals assigned for agricultural or forest reclamation,
- regulation of water conditions within the vicinity of disposals and abandoned workings and on adjoining terrains.

In a wide ranging reclamation activity the tendency (in order to improve the efficiency of operations) is to carry out these basic treatments during the course of performed mining activity.

Discussed in this paper are some aspects of restoration of the natural environment arising from the technology of belt conveyor transport.

USEFULNESS OF ENGINEERING SCHEME IN SHAPING OF DISPOSALS AND EXCAVATIONS

In Poland it is considered that, for an agricultural type of reclamation, one can utilize terrains with gradients less than 15 percent i.e. 1:7. Excessive flattening of the slopes is related to the reservation of greater areas for disposals or excavations, and hinders their drainage. The slopes usually are made more steep and are parted by horizontal terraces, or transportation benches, serving also to control surface waters. The tendency is to make slopes with 30 % percent gradients. In the grading of such slopes bulldozers can be used, without excessive wear of same.

As stated above the formation of slopes in the excavations the method of output transportation back from the working machines, as a rule, has no influence.

In high dumping with belt conveyor stackers, the slopes may be formed according to an optionally devised profile; then the additional grading to be carried out in the course of reclamation is limited only to levelling of uneven places.

In low dumping the possibility of manoeuvering with stacker boom terminal is limited by the range of the machine. With a required inclination of slopes 30 percent, with terraces of 5-6 m width, vertical spacings of 5-7 m and 20 m height of dump layer, the length of horizontal projection of the slope will come to 75 - 80 m. If the safe distance of the stacker axle from the top edge of the low dumped slope amounts to 50 m, then the minimal length of the stacking boom should be 130 m. Such booms have the biggest stackers (e.g. in the Bełchatów mine the A_2Rs-B-12500.95+BRs stacker has a parameter of only 95 m), also the profiling of 20 m high dump layers would entail loss of efficiency of the stacking machines (too often it would follow the shifting of overburden stacking belt conveyors, and with it the whole technological system). For this reason the profiling of low dumped slopes is usually done by bulldozers, and the volume of earth work is considerable, and may exceed 8 thous m^3/ha, even with the height of stacked layers being 20 m.

The planning of general inclinations on the crown top faces is possible in the course of designing. In the course of stacking with belt conveyor stackers there remain on the crown tops characteristic ridges and trenches resulting from the limited reach of the stacker and the travel of its boom. The stages travel of the boom is caused by belt conveyor shifting in the transport of overburden for longer distances than the definite width in flow sheet of low or high dump blocks. The width of the trench equals the excess of standarised belt conveyor shift in stacking in blocks, with employed maximum horizontal reach of the stacking boom. The depth of trench is:

$$h = \frac{s}{2k},$$

where: s = width of trench

k = cotangent of the dumped soil natural slope angle.

The ridges and trenches have shapes in plan corresponding to the slewing movement of the stacker boom terminal.

In order to determine the value of a single shift forward of the stacking boom terminal, it was assumed that the final grading of the crown top is made by truncation of ridges to half their height and the depths of trenches should not exceed the $1/2\ h = 0.50$ m value. So then this single shift may not be more than

$$p = 2\ h \cdot k$$

With $k = 1.5$ most frequently, the maximum shift of stacker boom terminal may amount to 3 m.

USEFULNESS OF MINE ENGINEERING SCHEME RESTORATION OF SOILS

Agricultural production requires the formation of near-to-surface layers from such types of soils where by in a relatively short time soils of minimum average fertility could be obtained. The procedure for such management of overburden is defined as the technical production of soils. Among the methods of technical production of soils selective storage of overburden and plays a fundamental role. The feasibility of soil production depends on:

a) usefulness of particular layers of overburden for formation of near to surface layers on a disposal

b) usefulness of particular elementary machines and of whole engineering systems in selective storage of overburden.

The overburden in Polish lignite surface mines is widely differentiated in respect of composition and properties, and this gives a wide diversification in reclaiming usefulness. The assessment of its suitability is carried out on the basis of a geological and pedological classification. Geological research concerns occurrences of distinct layers, their origin and hydrogeological conditions. Pedological research concerns the composition and properties of samples taken from particular distinquished overburden layers, also of samples of waters occurring in particular aquifers. Vegetation tests concern the observations of germination, growth, health conditions and yields of test plants grown in selected samples of soils.

Usefulness of particular elements of engineering systems for the technological production of soils was analysed on the basis of machines and systems working in Polish mines.

The working of overburden and of spoil benches is carried out with bucket wheet or chain excavators. The working with bucket wheel excavators in horizontal slice favours better disintegration excavated material and affords a better sorting of particular formations in the selective storage of overburden. Working in vertical slice gives a better mixing of solis from a given few thin layers, and this is very important in the model of steered storage of overburden presented below.

In working with bucket chain excavators on a rail undercarriage the degree of output disintegration depends on the methods of shifting and the shifting frequency of the excavator track and on the duty of the machine. In directed storage of overburden one acquires a uniform mix of the output coming from the entire exploitation cut. There is a small potentially for selective workings with crawler mounted excavators with sliding articulated booms.

The usefulness of belt conveyors for selective overburden transportation is dependent on the system of excavators interlocking with stackers. In the Konin open-pits the technological systems are functioning at present defined as monoblock-branching, in which two excavators feed overburden onto one collecting belt conveyor transporting it to one stacking machine. On this mother belt conveyor, material useful for good reclamation is obtained only when both excavators are working simultaneously with overburden suitable for reclamation needs. In the case of the shutting down of one excavator the system (the excavator-belt conveyor-stacker), becomes a mono-block, where a material suitable for soil production could be acquired. So that the belt conveyor can ensure delivery of selectively worked overburden to the stacker it must work in practice only in the situations described above. Such a solution cannot, however, be accepted due to the considerable cost of construction and of attendance of the belt conveyors in mono-block systems. For this reason one strives for the construction of mother belt conveyor lines, on which transportation of selected overburden masses would be connected with a simultaneous shutting down of excavators working other layers of overburden. In the system applied in the Bełchatów mine, the use of a sorting belt conveyor line will enable connection of appropriate series of excavators to optional stacking series. This may enable the displacement of optional overburden layers on the surface of disposal, and will help to locate the toxic tertiary formations in deep put of disposal. This enables to obtain top layers of disposal of better reclaiming usefulness.

In belt conveyor transport a selective storage is possible only in cases where the selected masses of overburden are supplied to stacking machine separately. There in only a limited chance of high stacking of disposal with thinner by two to three meters layer (when the delivered material not suitable for reclamation) and afterwards to grade the uneven surface by bulldozers; in these operations the better material could be placed on the top of disposal. In this situation stacked layers of such a height should be designed that the described operation could be feasible.

METHODS OF TECHNICAL PRODUCTION OF SOILS WITH BELT CONVEYOR TRANSPORT

By analysing geological structures of overburden one may easily state, that there is no possibility of such a division of spoils into exploitation levels, to enable selective working of desired amounts of potentially productive soils keeping the full capacity of mining equipment. For geological conditions of Polish coal deposits and for the feasibilities of technological systems, 2 methods of technical soil production have been designed:

1) covering with top soil,
2) directed management with overburden.

The first method is based on the gathering from the foreland of the openpit of adequate amounts of top soils and covering with it disposals, formed from toxic layers. This operation requires transport and stacking of top soil a distinct, auxiliary technological system. In these systems two alternative solutions are to be taken into account:

System I - loosening of soil and gathering into heaps with the use of bulldozers, loading with loaders transport with trucks and spreading on the top of reclaimed disposals with bulldozers

System II - based on scrapers, striping the top soil carrying it, and subsequently surfacing.

The method of directed management with overburden was elaborated for geological conditions in the Konin mine. Here the possibility was created of directing good overburden mass derived from one or two top levels of open-pits onto the highest levels of disposals. In this way there exists the chance of placing the toxic formations not suitable for reclamation deep in disposals. In the surface layers of disposals mixtures of suitable for reclamation quaternary formations are placed. Their suitability for reclamation was confirmed in analytical and vegetative investigations. This method does not cause any apparent decrease in the output of elementary technological machinery and does not require the creation of auxiliary systems. Therefore it is much more economic than cover with top soil described above.

OTHER FACTORS OF HAZARDS TO THE ENVIRONMENT

Physical-mechanical hazards to environment are:

a) dusting derived from excavating, transport, and storage operations,

b) air pollution caused by spontaneous combustion of coal residues in disposals, and of uncovered coal in the open-pit,

c) surface water pollution with mine waters and waters coming from drainage of disposals,

d) seismic waves, noise, and the scattering of rocks as a result blasting,

e) landslides of slopes of open-pits and disposals,

f) subsidence of terrains as a result of deep drainage of aquifers,

g) the noise caused by machines and transport systems mining and during repairs of said machines.

Biological-chemical hazards are:

a) liquidation of arable land in areas occupied for mining and for supporting activity,

b) effect of drainage on the change in use of arable land cultivation within the range of depression cone.

Belt conveyor transport allows the construction of deep surface mines of large capacity, thus, in some opinions, hazard to the environment seems to be greater here than in the mines with use of different machinery. So far no systematic investigations and calculations have be made in Poland to compare the extent of degradation of the environment with different exploitation technologies. It seems, however, that advantages of belt conveyors such as surmounting the differences in height with steeper routes and the large concentration of mining operations contribute to a decrease in area directly transformed as per unit of useful mineral out put. There is no need to build developed routes of rail or truck transport.

CONCLUSIONS

1. The use of mining systems with belt conveyor transport allows open-pit exploitation of deep deposits and allows the formation of high disposals of overburden, as well as continuous transport of out put up to 150 mil. m^3 per year from one pit; this can be not achieved in loose rocks by other system.
2. The use of belt conveyor transport does not require long and carefully prepared roads for trucks or rail output haulage; therefore the area of terrains occupied for development cuts and transport facilities, can be reduced.

3. In certain geological - mining conditions utilization of basic equipment for grading of disposals and for technical spoil production in the process of reclamation is possible.

4. It is recommended to carry out comparable studies of, the effects of surface mining with different technologies on the selected environment components.

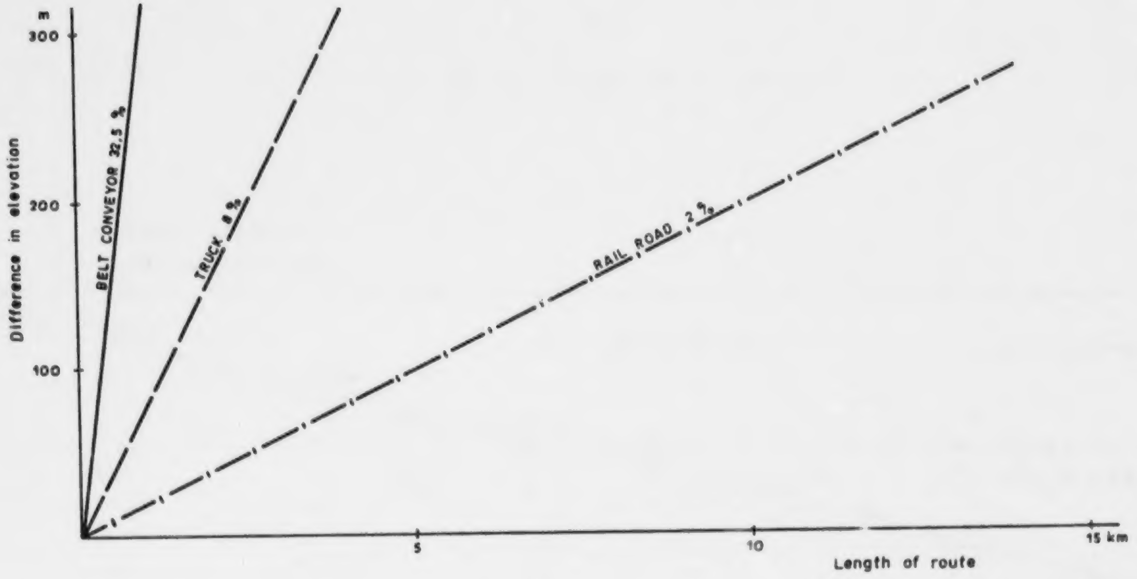


Fig. 1. Dependence of the length of haulback roads on the type of transport means

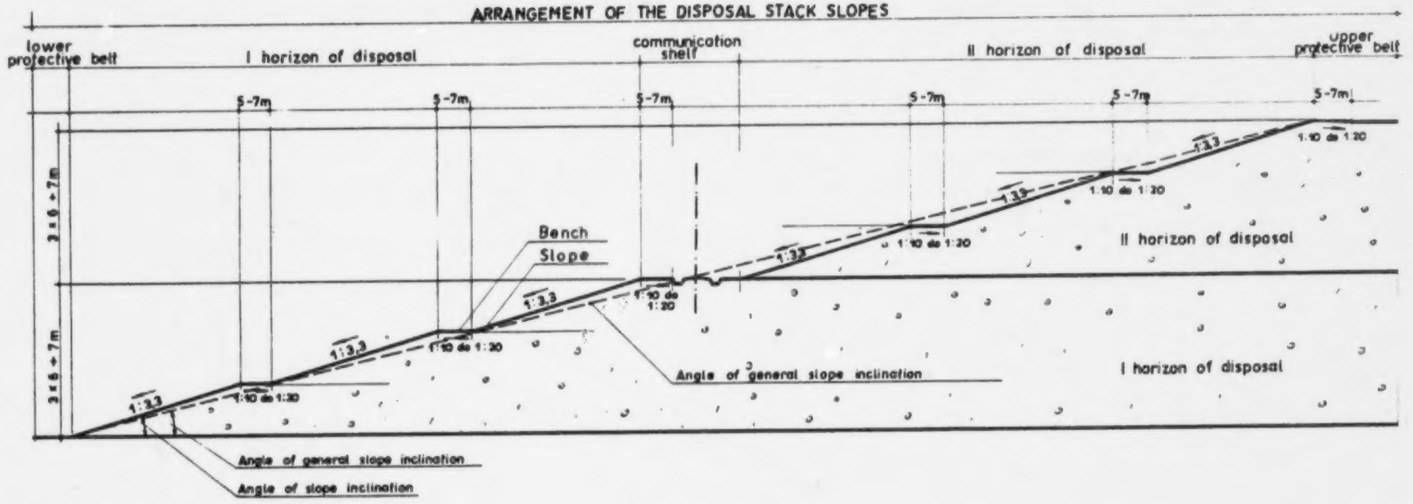

ARRANGEMENT OF THE DISPOSAL STACK SLOPES
lower protective belt
I horizon of disposal
communication shelf
II horizon of disposal
upper protective belt
5-7m
3×6÷7m
3×6÷7m
1:3,3
1:10 do 1:20
Bench
Slope
Angle of general slope inclination
Angle of slope inclination
II horizon of disposal
I horizon of disposal

Fig. 2. Formation of slopes - diagram

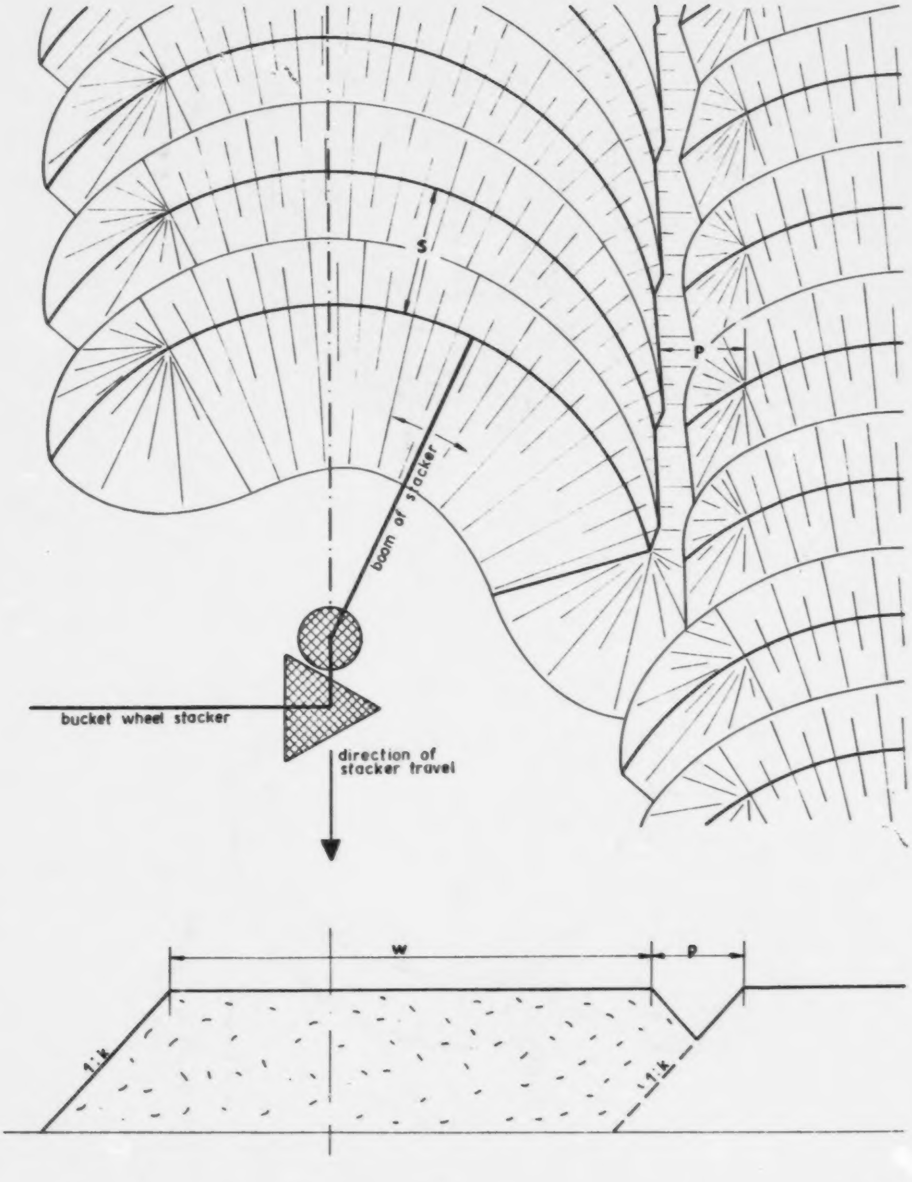

S
P
boom of stacker
bucket wheel stacker
direction of stacker travel
w
p
1:k
1:k

Fig. 3. Formation of spoil disposal top with the bucket wheel stacker in block operation

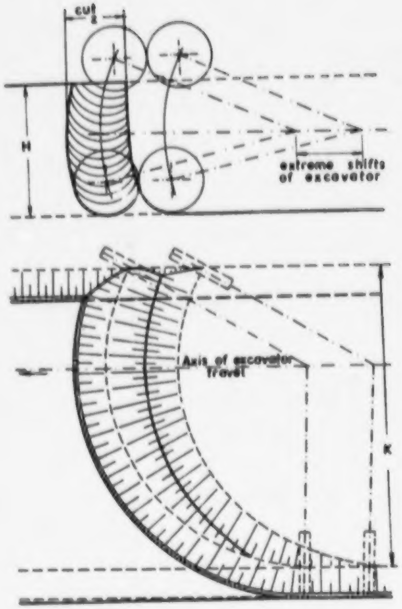

cut
z
H
extreme shifts of excavator
Axis of excavator travel
K

Fig. 4. Horizontal slice cut with bucket wheel excavator

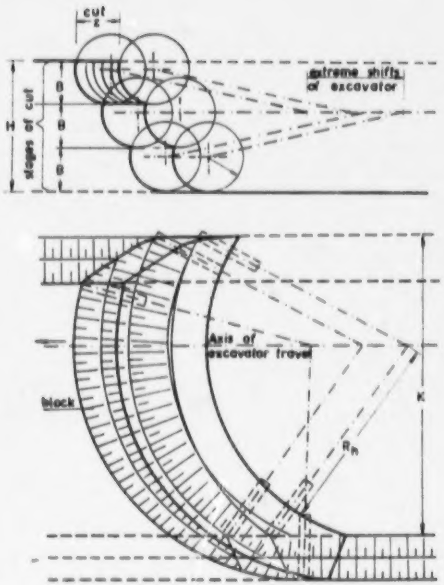
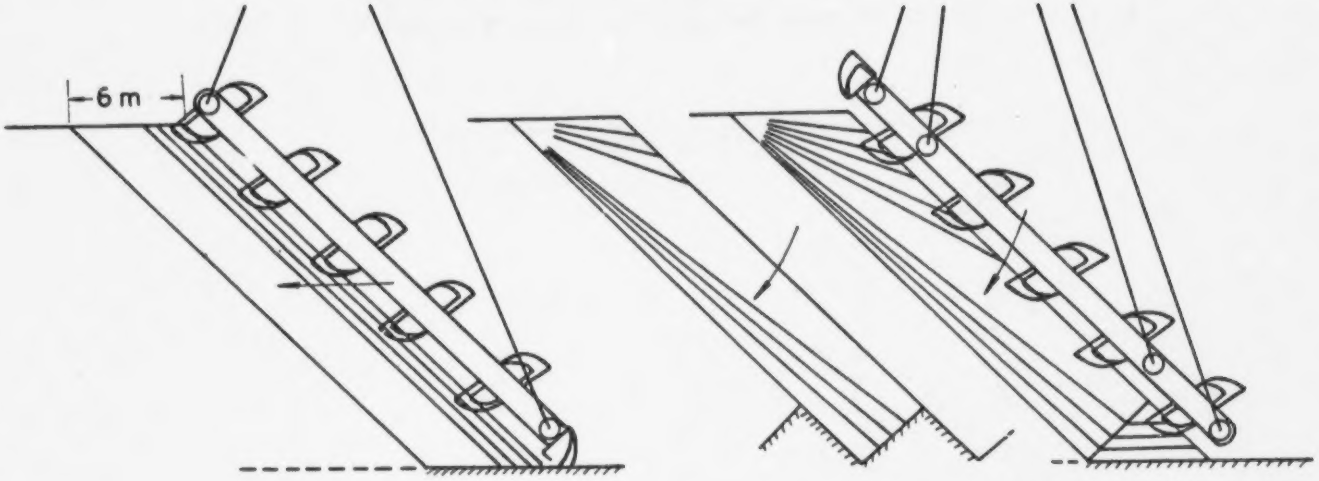

cut
z
H
stages of cut
B
B
B
extreme shifts of excavator
Axis of excavator travel
block
K
R_h

Fig. 5. Vertical slice cut with bucket wheel excavator



a) parallel working

b) fan-wise working

Fig. 6. Working with bucket chain excavator

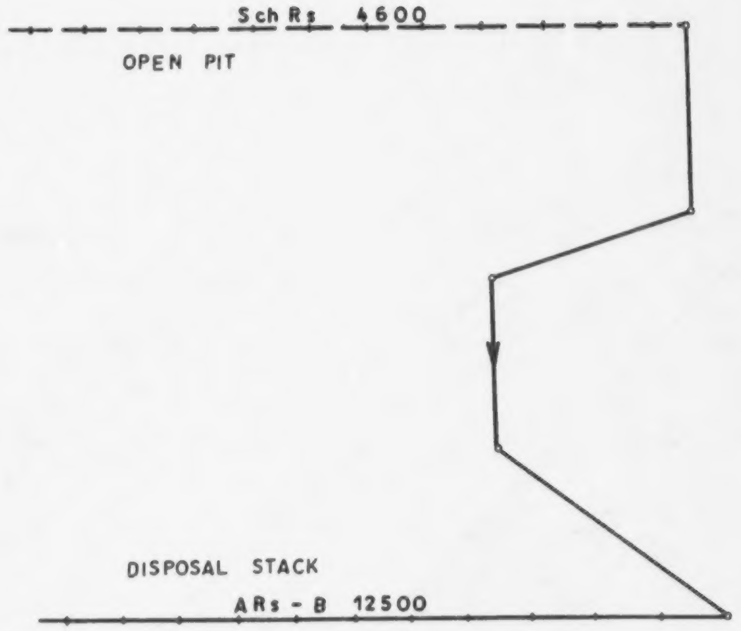

SchRs 4600
OPEN PIT
DISPOSAL STACK
ARs - B 12500

Fig. 7. Monoblock technological scheme of excavator - belt conveyor - stacker work

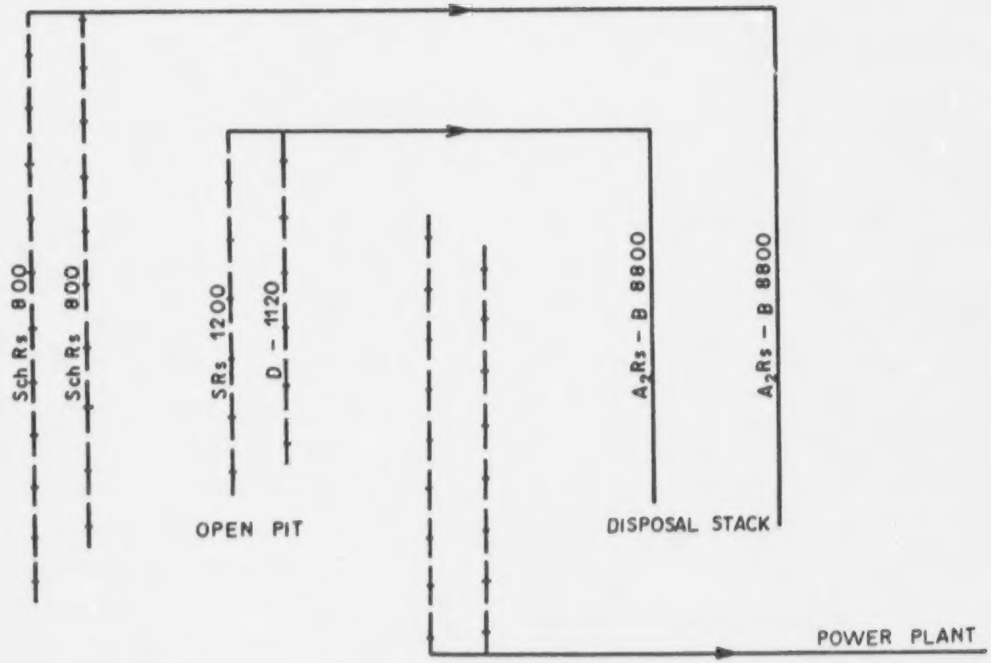

SchRs 800
SchRs 800
SRs 1200
D - 1120
OPEN PIT
A$_2$Rs - B 8800
A$_2$Rs - B 8800
DISPOSAL STACK
POWER PLANT

Fig. 8. Monoblock - branching technological scheme of excavator - belt conveyor - stacker work

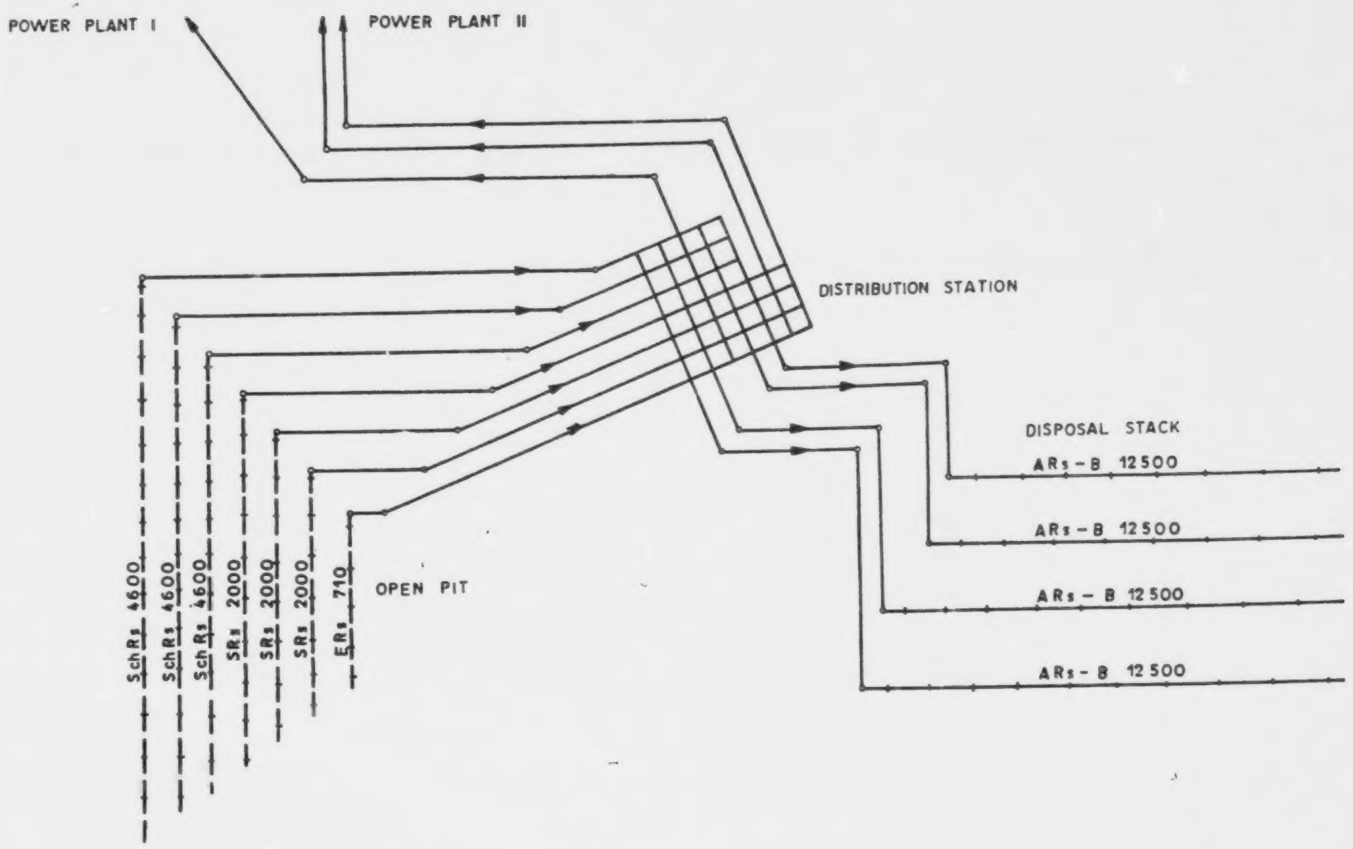

POWER PLANT I
POWER PLANT II
DISTRIBUTION STATION
DISPOSAL STACK
ARs-B 12500
ARs-B 12500
ARs-B 12500
ARs-B 12500
SchRs 4600
SchRs 4600
SchRs 4600
SRs 2000
SRs 2000
SRs 2000
ERs 710
OPEN PIT

Fig. 9. Excavator - belt conveyor - stacker scheme with distributing belt conveyor

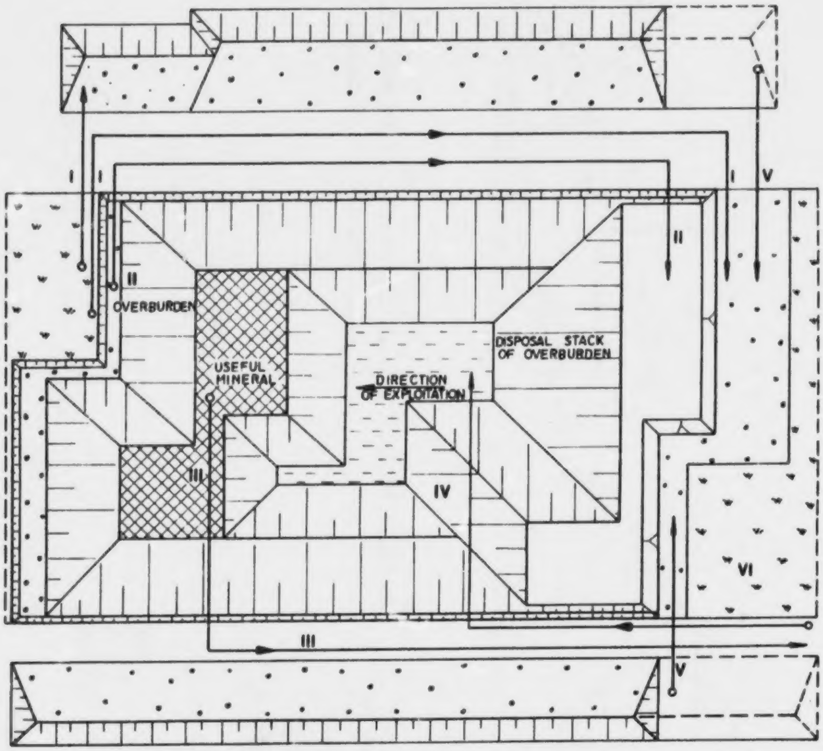

I
I
I
V
II
II
OVERBURDEN
USEFUL MINERAL
DIRECTION OF EXPLOITATION
DISPOSAL STACK OF OVERBURDEN
III
IV
VI
III
V

Fig. 10. Model of spoils covering with top soil.

(I - Removal of humus layer;
II - Removal of remaining parts of overburden;
III - Exploitation of useful mineral;
IV - Spoil disposal; V - Covering graded of disposal with top soils; VI - fertilization, agrotechnical treatments, introduction of vegetation).

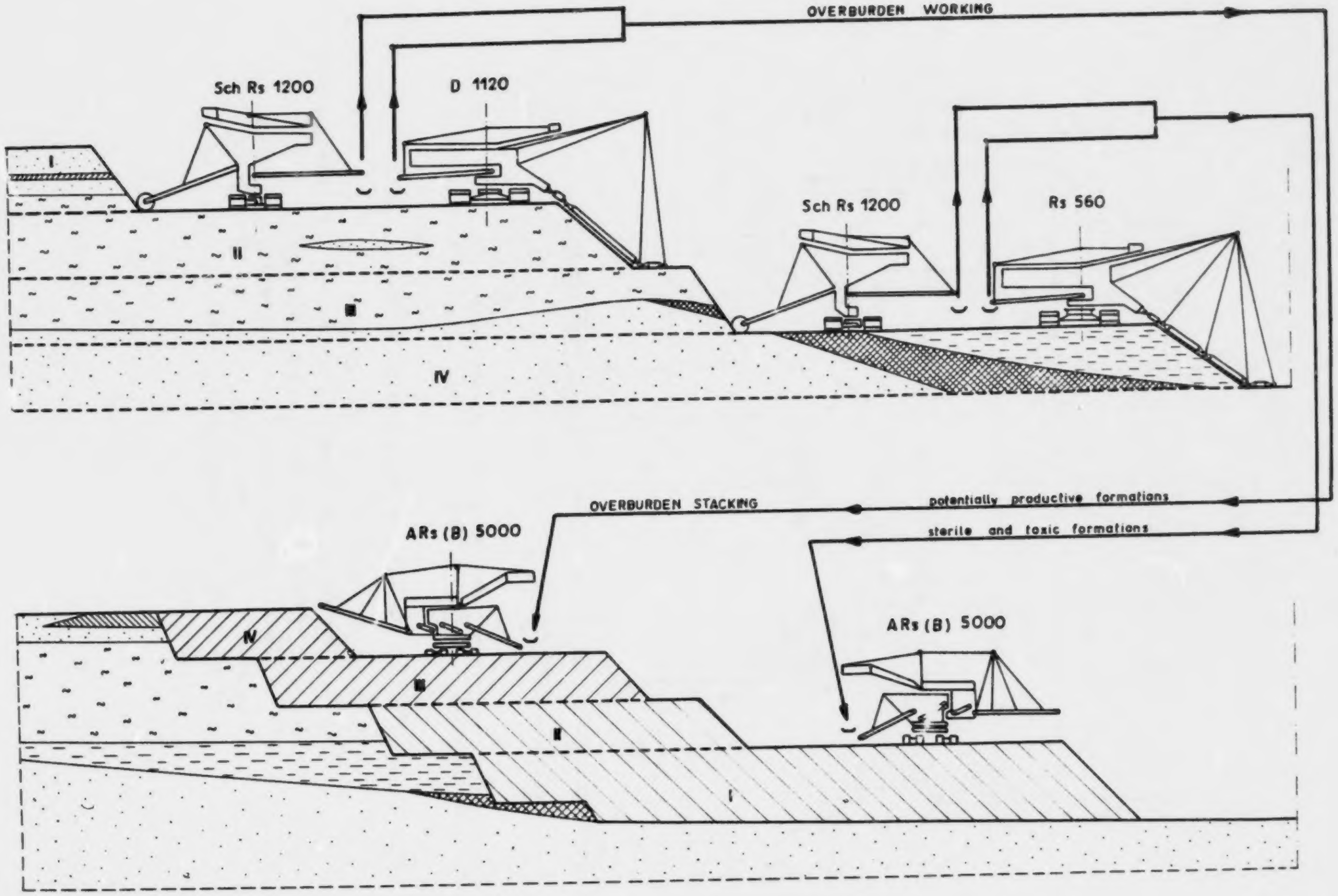

OVERBURDEN WORKING
Sch Rs 1200
D 1120
Sch Rs 1200
Rs 560
I
II
III
IV
OVERBURDEN STACKING
potentially productive formations
sterile and toxic formations
ARs (B) 5000
ARs (B) 5000
IV
III
II
I

Fig. 11 Model of selective overburden management

COAL MINING AND GROUND WATER

by

John Hardaway x/

INTRODUCTION

Coal mining has the potential to measurably disrupt local ground water systems. In addition, coal mining on a regional scale may disrupt regional ground water systems. Both surface mining, which requires removal and thus extensive disturbance of overburden, and underground mining have this disruption potential. In-situ extraction also has a high potential for disruption of ground water systems. The extent and tenure of such disruptions will vary, often in proportion to the size of the mine and the degree of hydrologic complexity of the ground water system. Documented impacts to the ground water system have included lowered water tables and deterioration of water quality.

The objectives of this paper are to discuss the potential effects of coal mining on ground water systems and to report on the measurement of such effects by others. It should be noted that the documentation of such efforts as they relate to coal mining in the United States is limited. Perhaps one reason for this limited documentation is the fact that until the last four years, affected ground water systems have not been thorounghly evaluated. To date the majority of reported data has dealt with acid and iron production from the oxidation of sulfide minerals associated with coal mining activities in the Eastern and Midwestern United States. It is hoped that the recentlypassed Surface Mining

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x/ John Hardaway - Physical Science Administrator. Office of Energy US EPA, Region 8, Denver Col. 80203.

Control and Reclamation Act of 1977 (Public Law 95-87) will serve to improve future efforts to evaluate the ground water impacts of coal mining in the United States.

Potential disruptions of the ground water system brought about by coal mining may be divided into "physical impact" and "chemical impacts". Hamilton and Wilson (1977) prepared a generic analysis of the effects of the surface strip mining of coal which emphasized the theoretical impacts of this mining on the ground water flow system. McWhorter et. al. (1977) also reported on the possible effects on the flow system. This paper makes use of Hamilton and Wilson's analysis in addition to textbook presentations of ground water flow systems such as those contained in standard texts.

PHYSICAL IMPACT

The geohydrologic setting in the vicinity of coal seams is varied. (See Figure 1) Coal seams may like anywhere within the regional recharge-discharge system. The coal may be overlain or underlain by significant ground water aquifers. The coal itself may be part of an aquifer. In most cases, the older the coal, the less will be its water transmission capabilities since it is denser and less likely to contain open fractures. The majority of the ground water found in coal seams flows through the fractures in the coal, rather than through the coal matrix itself since the internal permeability is low.

Underground mining and the first stages of surface mining, namely the excavation of overburden and coal, both create a void in the geologic system which then affects the ground waters system by forming a "sink". If saturated strata are encountered in a mine, the active mine will lower the piezometric surface at the mine itself, usually to the bottom of the active mine area. Seldom are conditions in the United States such that dewatering wells are required and thus the active mine pit itself serves as a large well and causes a cone of depressions in the piezometric surface. The horizontal extent of this depression is predictable and has ranged from a few hundred to a few thousand

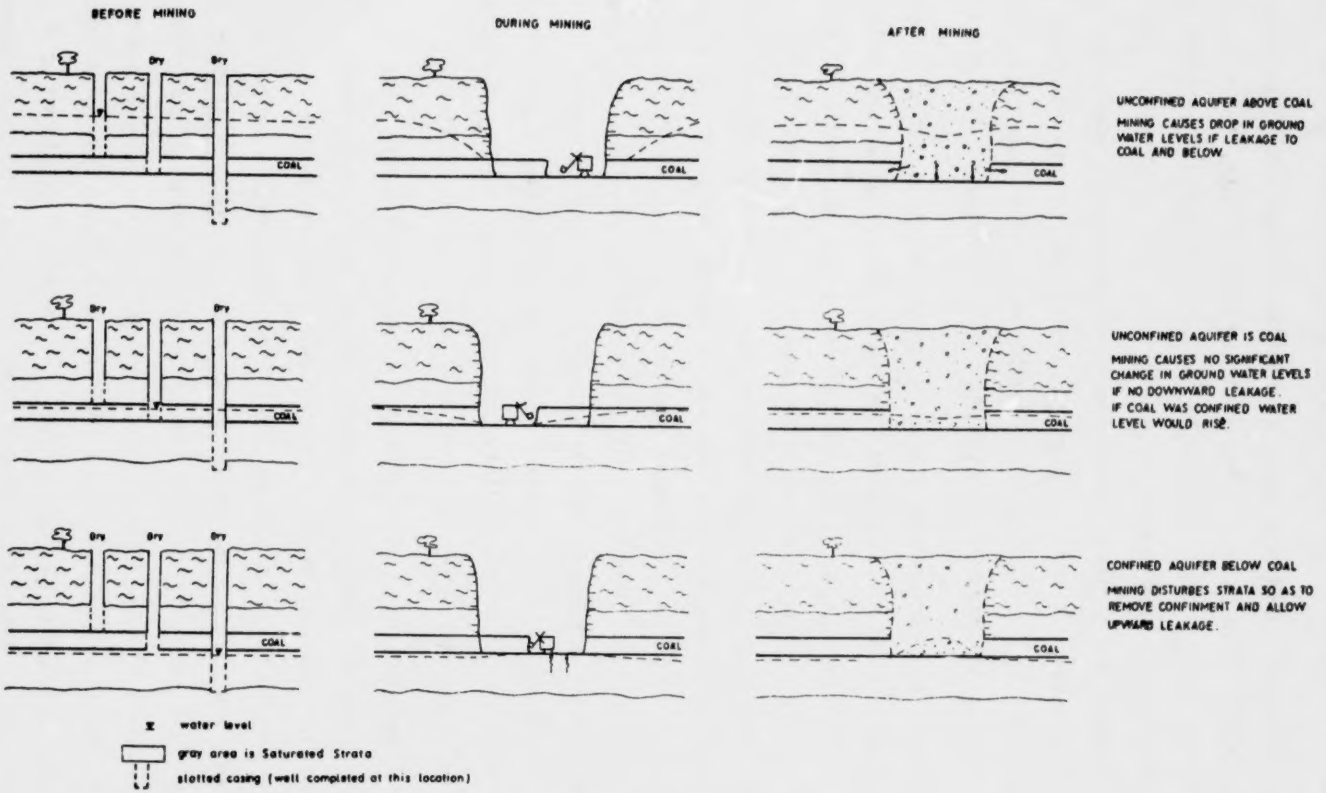

BEFORE MINING
DURING MINING
AFTER MINING
Dry
Dry
COAL
COAL
COAL
UNCONFINED AQUIFER ABOVE COAL
MINING CAUSES DROP IN GROUND WATER LEVELS IF LEAKAGE TO COAL AND BELOW
Dry
Dry
COAL
COAL
COAL
UNCONFINED AQUIFER IS COAL
MINING CAUSES NO SIGNIFICANT CHANGE IN GROUND WATER LEVELS IF NO DOWNWARD LEAKAGE.
IF COAL WAS CONFINED WATER LEVEL WOULD RISE.
Dry
Dry
Dry
COAL
COAL
COAL
CONFINED AQUIFER BELOW COAL
MINING DISTURBES STRATA SO AS TO REMOVE CONFINMENT AND ALLOW UPWARD LEAKAGE.
water level
gray area is Saturated Strata
slotted casing (well completed at this location)

Fig.1 GENERALIZED GEOHYDROLOGIC SETTINGS

meters from the active mine. This distance is a function of the permeability and the storage coefficient of the surrounding geologic strata as well as the premining ground water gradient through the mine area.

Three hydrogeologic situations are identified for purposes of examing the physical impacts of mining saturated strata. These are (1) saturated strata above the coal, (2) saturated strata including the coal, and (3) saturated strata below the coal. In the first two cases, the drawdown caused by active mining may be approximated by an appropriate potentiometric equation. The accuracy of the prediction depends on the degree to which pre-mining hydrologic measurements have described the hydraulic complexity of the ground water flow system.

In the case of saturated strata above the coal, mining will generally cause these strata to be drained. Reclamation may allow reestablishment of the piezometric surface if the disturbed area is small in relationship to the size of the ground water flow system. If, however, the disturbance is relatively large, and the transmissivity of the reclaimed area is high, the piezometric surface of the overlying strata may be permanently lowered. In the case where saturated strata occur at the level of the coal seam, the piezometric surface will generally be lowered during mining. However, following mining a trend toward re-establishment of the piezometric surface should take place. If saturated strata exist below the coal seam, they will be affected if they contain water under sufficient pressure to cause the water to flow upward into the mined area.

It would appear from the literature available that only in limited cases in the interior western United States has there been adequate ground water monitoring during coal mining to document the drawdown effect of coal mining. In addition, all of monitoring reported in the literature has been performed at surface mine sites. Hamilton and Wilson (1977, page 22) report that the large surface mining operation conducted along Caballo Creek in eastern Wyoming (the AMAX Belle Ayr Mine) has not produced drawdown past 300 meters from the mine edge. Van Voast and Hedges (1975, Plate 9) report drawdown out to at least 3.2 kilometers from the edge of the Decker mine (in the up-gradient direction).

As surface mining progresses, disturbed and broken overburden is returned to the mine and the ground water system begins to approach some physical equilibrium with the disturbed material. In the case of most underground mining, the hydrologic equilibrium reached after the mining is likely the same as that produced during mining since no material is back-stowed into the mined-out seam to fill the void and since adits will in many cases permit continued drainage to the surface. While active surface mining causes voids with infinite permeability, subsequent backfilling again gives a finite value to permeability in the mined area. It is postulated that the postmining permeability of backfilled areas in the majority of cases will be greater than that existing prior to mining. This does not mean to infer that the surface infiltration rate in most cases will be greater since impermeable surfaces may be created if the spoiled overburden surface is inadequately treated. However, unless spoiled overburden is selectively placed, overburden moisture is controlled, and heavy equipment is used for compaction, it is belived that permeability cannot be reduced to that created over geologic time by pressure and chemical action. An exception occurs in those areas of the Midwest and West of the United States where the undisturbed overburden is not indurated. Van Voast et. al. (1975) have graphically portrayed ranges in hydraulic conductivity for coal and spoil aquifers at surface coal mines located near Colstrip and Decker, Montana. These are repeated here as Figure 2. Rahn (1976 pp 26-31, 54) has indicated that hydraulic conductivities of spoil measured in the vicinity of Sheridan, Wyoming probably will never approach the values of natural formations (i.e., hydraulic conductivities are always higher).

McWhorter et. al. (1977, pp 91) presented a streamflow equation that was used to project postimining flow patterns. The equation may be used to project streamflow affected by surface coal mining as follows:

Stream functions outside the disturbed area are described by

$$\Psi = q_{\infty} y \quad 1 - \left(\frac{k_o - k_i}{k_o + k_i}\right) \left(\frac{R^2}{x^2 + y^2}\right)$$

Stream functions inside the disturbed area are described by

$$\psi_i = \left(\frac{2q\ k_o}{k_o + k_i}\right) Y$$

The Notations are:

q_∞ = solution flux

k_o = hydraulic conductivity of undisturbed strata located outside the mine

k_i = hydraulic conductivity of spoil

R, x, y = the coordinates

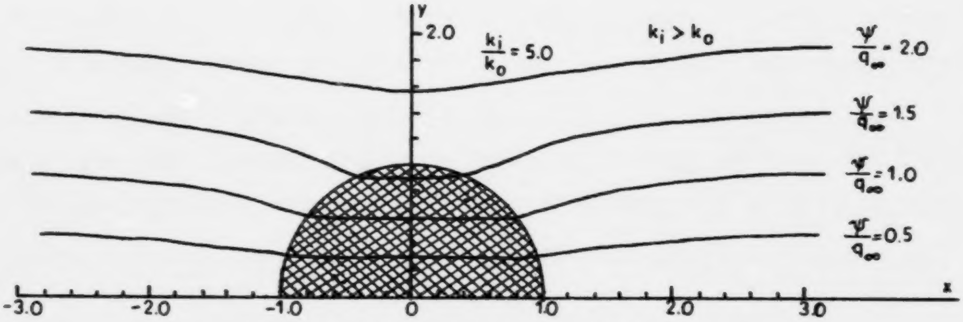
McWhorter et. al. used a circular mine area and assumed a simple hydrologic flow system of two-dimensional, steady flow. The stream function outside the disturbed area is controlled by the following term:

$$\left|\frac{k_o - k_i}{k_o + k_i}\right| \quad \frac{R^2}{x^2 + y^2}$$

which is set equal to "C" where C is treated as a decimal measure of the significance of the differences between premining and postmining streamflow functions.

The perimeter of the area within which the flow paths are is significantly modified forms a circle of radius "r" given by:

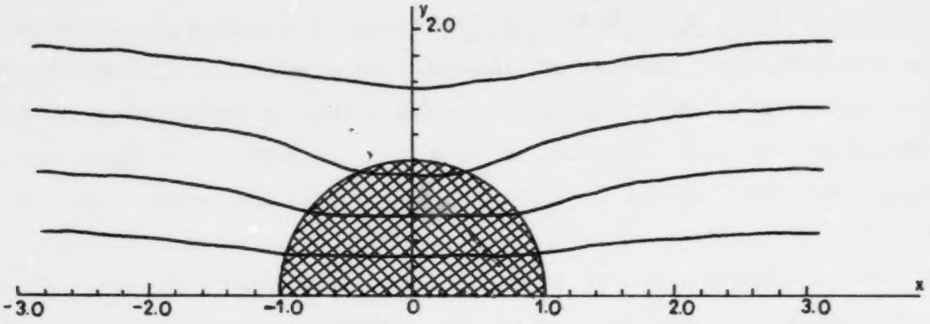
$$r = x^2 + y^2 = \frac{R}{\sqrt{C}} \left(\frac{k_o - k_i}{k_o + k_i}\right)^{1/2}$$


y
2.0
$\frac{k_i}{k_o} = 5.0$
$k_i > k_o$
$\frac{\psi}{q_\infty} - 2.0$
$\frac{\psi}{q_\infty} = 1.5$
$\frac{\psi}{q_\infty} = 1.0$
$\frac{\psi}{q_\infty} = 0.5$
x
-3.0
-2.0
-1.0
0
1.0
2.0
3.0

Flow pattern in a disrupted aquifer, $k_i / k_o = 5$

k_i = inside mine area

k_o = outside mine area



0 if ki = 2 ko and we assume
that C=5% or C=05,
then r=2.6R where R = radius of mine

0 if $k \rightarrow 0$ or ∞ , $r \rightarrow \frac{R}{\sqrt{c}}$

Thus the effects of mining are projected as minimal part of radius of 2.6 times the radius of the mine. Rogowski et. al. (1977) observe that many air pockets (i.e., large voids) are evident in mine spoils. They point out that these voids may contribute to non-Darcian flow behavior of the spoil. This heterogeniety of the spoil maybe further complicated by the existence of respred topsoil on top of coarser spoil. Thus the wetted front that occurs as a result of infiltration may be unstable (Hill and Parlange, 1972, cited in Rogowski et. al., 1977).

Data provided by Gilly et. al. (1977) show how water movement into spoils can be significantly and positively affected by tilling (i.e., cultivating) the spoil.

Thus water movement through spoils may not be as simplistic as assumed, and anomalous flow patterns may be found.

CHEMICAL IMPACTS

Major consideration has been given by the research community to the effect of coal mining and reclamation on ground water quality (at least as that quality subsequently affects the surface water system). McWhorter (1977), Dollhopf et. al. (1977). Van Voast and Hedges (1975)

Van Voast, (1974) and Rahn (1976); have addressed, in varying degrees, potential and measured effects. Ground water quality impacts during mining are not considered to be particularly significant due to the fact that the mine acts as a sink for ground water flow and the chemical changes in the quality of the interrupted water are relatively small since the active mine is kept as dry as possible during operations and discharged water is treated to meet water quality effluent limitations. However, when mining is completed, water infiltration and saturation of the mined area will likely reoccur and ground water quality will be changed. The reaction of sulfide minerals with oxygen and water is well documented (Ohio State University Research Foundation, 1971). In the case of pyrite, an idealized chemical reaction is:

$$2\ FeS_2 + 70_2 + 2H_20\ \ 2\ FeS0_4 + 2H_2S0_4$$

This is a characteristic reaction in coal bearing formations with a pyrite content of more than a few percent, where neutralizing carbonates are in short supply, and where water is readily available. Thus, thus chemical reaction is persuasive with respect to coal mining in much of the eastern and midwestern United States. Interestingly, acid formation had been either ignored or overemphasized in the coal mining regions of the western United States until the past year. At this time certain researchers including Croft, et. al. (1977) have identified oxidation of sulfide minerals and formation of sulfuric acid as a key step in the commonly observed increase in alkalinity caused by coal mining in the interior western United States. The chemical reactions, as identified by Croft, and others in ground water associated with a lignite mine in North Dakota, are caused by rain water (containing $Ca\ (HC0_3)_2 + 0_2$) as this water passes through the lignite are:

$$2\ FeS_2+70_2+2H_20\ \ 2FeS0_4+2H_2S0_4$$

and $Ca(HC0_3)\ _2+H2S0_4\ \ CaS0_4+C0_2+H_20$ and $CaC0_3 + H_2S0_4$

$$Ca(HC0_3)_2+ CaS0_4.$$

An additional source of SO_4 is through dissolution of gypsum. The water then becomes saturated with $CaSO_4$. However, if it flows through a sodium clay, the calcium is exchanged for sodium (cation exchange) resulting in water with a high $NaSO_4$ content (and high in HCO_3).

Rogowski et. al. (1977) note that a considerable amount of clay must be present and that it must possess a high exchange capacity to significantly alter the acid character of acid drainage from pyrite-rich strata. The hydrogen ions react with the crystal lattice to produce charged aluminium species. The lauminum will then be dissolved to some degree.

Pagenkopf et. al. (1977) have tabulated water quality data for two mine areas in Montana. Table 1 shows increased concentrations for a number of parameters. As indicated in Table 1, iron and pH tend to change much less than do the other common elements shown. Dollhopf, et. al. (1977) have found somewhat high concentrations of manganese in some ground water in spoils at one mine site. However, the natural levels of manganese also appear high suggesting that the coal mining may not be the source of high manganese water.

McWhorter et. al. (1977, pp 41) also noted sporadically high concentrations of manganese in Colorado streams and suggested, in the case of high manganese in ground water passing through spoils, that the source was older spoils (ca year or more) and a time delays in manganese dissolution.

Thorstenson, Fisher, and Croft are reported by Feder and Saindon, 1976 to have found that as ground water moves naturally downdip from recharge areas, a combination of chemical reactions with clays, sulfate-reducing bacteria, and other minerals gradually causes a change in the water of one of the Fort Union aquifers of Montana (the Fox Hills) from a Ca^{++} Mg^{++} HCO_3SO_4 type with a pH of about 8.0 to a $Na\,HCO_3$ - type with a pH above 8.5. Feder et. al. (1977) utilized data from nineteen randomly-selected wells in supporting this generalization showing statistically that Na, pH, HCO_3 and TDS tend to increase together in natural ground waters of the Fort Union, while SO_4, Ca and Mg tend to decrease in relative relationship.

TABLE 1

Comparison of Natural Ground Water and Spoil Waters in Southeastern Montana

	Decker		Colstrip	
	Wells	g.w. in spoil	Wells	g.w. in spoil
Ca	3.2	31	35	429
Mg	0.9	13	70	
Na	445	1355	27.4	346
$HC0_3$	1143	1996	366	655
$C0_3$	0	19	0	0
S0y	4.7	1320	118	3306
$Si0_2$	8.6	8.6	15	21
C1	15.3	16	4.3	63
TDS	1626	4801	641	5380
SPC	1590	5010	776	5300
Fe	0.02	0.02	0	0.85
pH	8.1	8.3	8.1	7.6

Pagenkopf, Whitworth, and VanVoast

The data developed by Feder et. al. are repeated here as Tables 2 and 3 to characterize the geochemistry of ground water from the Fort Union Formation in eastern Montana and western North Dakota. These data give background conditions for the area studied, and show the natural changes in water quality that must be separated from changes caused by coal mining and reclamation. Pietz et. al., (1974) through a ground water study conducted at a surface mining site in Illinois, identified changes in ground water quality similar to those found in the western United States. Ground water collected from the mine spoils contained significantly higher concentrations of sulfate, sodium, calcium, magnesium, manganese, and iron than did ground water collected from undisturbed sites (see Table 4).

Regardless of the climate or geographical region in which coal mining is conducted, mining processes, both surface mining and underground mining, expose fresh rock surfaces to an oxidizing environment. After some as yet undetermined time period of time, this oxidation potential should be satisfied. From Pagenkopf et. al., it's estimated that certain freshly-broken spoils collected in the western United States will require four volumes of pore water before the oxidation potential is satisfied to the degree that the additional waters passing through the spoils show little changes in dissolved solids content. The period of time for the oxidation potential to be satisfied then depends on the rate that water is available. McWhorter et. al. (1977, pp 5) suggest that the effects of leaching of spoils will not become apparent until about one pore volume of water passes through the spoil, thus in the more arid climates, where recharge to saturated aquifers does not excees a few centimeters a year, a long time period would occur before the effects of leaching are noticeable in terms of a measureable increase in total dissolved solids. Laboratory experiments conducted by McWhorter et. al. (1977, pp 59) on a spoil specimens collected in Colorado gave the results shown in Figure 3. Samples were collected for total dissolved solids analysis after passing 100 ml samples. Fresh water was continually added to maintain a head of 5 cm during the test. The spoil was aerated three times during the test, and the results suggest that 6.8 m^3 of deionized water must pass through 1 m^3 of spoil material to achieve a 95 percent reduction inconductivity. McWhorter et. al. use an example of spoils 20 M thick requiring 136 m^3 of water per square meter for leaching to achieve a 95 percent reduction in the original (high) conductivity. At an infiltration rate of 10 cm, it would then take 680 years to reduce conductivities by 95 percent and longer if the effects of weathering are considered (McWhorter et. al., 1977 pp 60). These leaching studies produced at least 2.4 kg of SO solubilized elements per cubic meter of spoil.

Table 2

Chemical analyses of samples representing a typical recharge water (sample A) and a typical discharge water (sample B) in the Powder River coal region
After Feder et. al. 1977

Parameter	Sample A	Sample B
Ca (mg/L)	180	1.9
Mg (mg/L)	82	.6
Total hardness (as $CaCO_3$) (mg/L)	790	7
HCO_3 (mg/L)	362	1,150
Na (mg/L)	250	450
SO_4 (mg/L)	1,100	5.5
SAR	3.9	73
pH	6.8	8.3
TDS (mg/L)	1,830	1,110
SiO_2 (mg/L)	11	7.8
Cl (mg/L)	6.1	47
K (mg/L)	9.3	1.5
F (mg/L)	.5	14
I (mg/L)	<.01	.07
Br (mg/L)	.1	.7
Al (µg/L)	20	20
As (µg/L)	<1.0	<1.0
Ba (µg/L)	<6	100
B (µg/L)	80	240
Cd (µg/L)	<1.0	<1.0
Cu (µg/L)	6	<5
Fe (µg/L)	2,500	30
Hg (µg/L)	<.1	<.1
Pb (µg/L)	180	15
Li (µg/L)	40	20
Mn (µg/L)	2,200	10
Mo (µg/L)	<12	12
Se (µg/L)	<1.0	<1.0
Sr (µg/L)	2,000	160
Zn (µg/L)	40	200
U (µg/L)	.30	.09
Ra (pCi/L)	.1	.2

1/ Sodium adsorption ratio.

Table 3

Geochemical summary of ground water from the Powder River coal region, Montana and Wyoming. After Feder et.al. 1977
(Detection ratio: number of samples in which constituent was determined to total number of samples analyzed.)

Parameter	Detection ratio	Geometric mean	Geometric deviation	Maximum	Minimum
Al (µg/L)	19/19	17	1.9	60	6.0
Ba (µg/L)	9/15	24	2.7	128	6.0
B (µg/L)	19/19	148	2.2	422	32.0
Cu (µg/L)	4/19	-	-	14	1.0
Li (µg/L)	20/20	36	2.4	180	10.0
Sr (ug/L)	15/16	444	4.1	2,754	19.0
As (µg/L)	6/20	-	-	6	1.0
Se (µg/L)	5/20	-	-	12	1.0
Cd (µg/L)	3/20	-	-	1	1.0
Hg (µg/L)	4/20	-	-	.2	.10
Zn (µg/L)	20/20	50	5.5	1,800	.70
Fe (µg/L)	20/20	170	10.5	28,000	7.0
Mn (µg/L)	20/20	21	9.5	4,800	.70
Br (mg/L)	13/20	.15	2.0	.7	.10
F (mg/L)	20/20	.68	2.8	14	.10
I (mg/L)	4/20	.01	1.4	.02	.01
Cl (mg/L)	20/20	8.7	2.1	47	1.9
SO_4 (mg/L)	20/20	292	5.1	1,800	5.5
HCO_3 (mg/L)	20/20	504	1.6	1,400	195.0
Ca (mg/L)	20/20	24	6.5	530	1.9
Mg (mg/L)	20/20	13	7.0	150	.60
K (mg/L)	20/20	3.9	2.0	12	1.5
Na (mg/L)	20/20	173	3.0	1,000	24.0
SiO_2 (mg/L)	20/20	11	1.6	26	5.8
THD (mg/L)	20/20	112	6.9	1,900	7.0
pH1/	20/20	7.7	.6	8.5	6.5
Specific conductance (mhos/cm)	20/20	1,494	1.8	4,000	582.0
TDS (mg/L)	20/20	1,076	1.9	3,190	345.0
$NO_3 + NO_2$ (mg/L)^2	18/20	.08	8.3	3.2	.01
SAR 2/	20/20	6.9	6.0	73	.40
Ra (pCi/L)	17/18	.23	2.0	.80	.10
U (ug/L)	16/18	.25	6.0	7.3	.01
Beta (pCi/L as Cs-137)	12/18	6.6	1.8	14	4.0

1/ Arithmetic mean and standard deviation.

2/ Sodium adsorption ratio.

Table 4. Means and ranges of groundwater chemical characteristics for monthly samples collected during 1971-1973 from selected placed land and mine-spoil monitoring wells at the Fulton County, Illinois Land Reclamation site.[1] Pietz et. al., 1974

Chemical Characteristic	MDL[2]	Placed Land Wells		Mine-Spoil Wells		T-test for Means[3]
		Range	Mean	Range	Mean	
pH		6.40 - 8.90	7.48 ± 0.03[4]	6.20 - 8.90	7.19 ± 0.03	x x
Total P, mg/l	0.01	0.00 - 2.10	0.14 ± 0.02	0.00 - 0.41	0.08 ± 0.01	x
Cl^-, mg/l	1.0	0.00 - 87.0	11.9 ± 1.0	2.0 - 44.0	17.5 ± 0.6	x x
$SO_4^=$, mg/l	1.0	0.0 - 1253	127 ± 15	21.0 - 1812	609 ± 32	x x
Kjeldahl N, mg/l	1.0	0.00 - 6.50	1.22 ± 0.10	0.00 - 7.30	1.65 ± 0.21	x x
NH_3-N, mg/l	0.1	0.00 - 4.00	1.04 ± 0.07	0.00 - 6.90	1.25 ± 0.06	n.s.
NO_3+NO_2-N, mg/l	0.01	0.00 - 30.5	0.82 ± 0.30	0.00 - 0.43	0.05 ± 0.01	x x
Alkalinity, mg/l	1.0	110 - 700	363 ± 10	100 - 1600	661 ± 19	x x
E.C., umhos/cm		200 - 1500	786 ± 90	1000 - 4000	2406 ± 63	x x
K, mg/l	1.0	0.0 - 20	1.5 ± 0.2	2.0 - 18.7	8.3 ± 0.3	x x
Na, mg/l	1.0	7.0 - 131	30.4 ± 1.9	19.0 - 657	246.8 ± 14.4	x x
Ca, mg/l	1.0	38.5 - 226	103.2 ± 3.3	35.0 - 707	260.3 ± 13.6	x x
Mg, mg/l	1.0	23 - 102	56.8 ± 1.6	86.0 - 625.0	207.4 ± 8.8	x x
Zn, mg/l	0.1	0.0 - 140	8.2 ± 1.2	0.40 - 100.0	14.5 ± 1.5	x x
Cd, mg/l	0.01	0.00 - 0.03	0.002 ± 0.001	0.00 - 0.20	0.010 ± 0.002	x x
Cu, mg/l	0.01	0.00 - 0.82	0.04 ± 0.01	0.00 - 0.52	0.06 ± 0.01	n.s.

Table 4. (Cont'd) Means and ranges of groundwater chemical characteristics for monthly samples collected during 1971 - 1973 from selected placed land and mine-spoil monitoring wells at the Fulton County, Illinois Land Reclamation site. 1

Pietz et. al., 1974

Chemical Characteristic	MDL[2]	Placed Land Wells		Mine-Spoil Wells		T-test for Means[3]
		Range	Mean	Range	Mean	
Cr, mg/l	0.02	0.00 - 0.04	0.003 ± 0.001	0.00 - 0.05	0.008 ± 0.001	x x
Ni, mg/l	0.1	0.00 - 0.30	0.02 ± 0.005	0.00 - 1.10	0.08 ± 0.01	x x
Mn, mg/l	0.01	0.21 - 2.79	0.86 ± 0.04	0.39 - 9.00	2.53 ± 0.22	x x
Pb, mg/l	0.03	0.00 - 0.44	0.08 ± 0.01	0.00 - 0.66	0.15 ± 0.01	x x
Fe, mg/l	0.1	.0 - 78.8	17.3 ± 1.0	2.70 - 1930	52.1 ± 3.4	x x
Al, mg/l	1.0	0.0 - 5.8	0.8 ± 0.1	0.0 - 8.20	0.8 ± 0.2	n.s.
Hg, μg/l	0.1	0.00 - 1.40	0.17 ± 0.02	0.00 - 2.40	0.22 ± 0.02	n.s.

1. Groundwater data from six placed land and six mine-spoil monitoring wells were used.

2. MDL is the minimum laboratory detection limit.

3. The use of ^{x} denotes significance at the 0.05 level, ^{xx} denotes significance at the 0.01 level, and n.s. denotes not significant.

4. Standard error of mean, $S_{\bar{x}} = S/\sqrt{n}$, where S is the standard deviation and n is the sample population.

Pagenkopf et. al. (1977) also performed laboratory experiments for the purpose of analyzing the leachates from spoil. They concluded, from the data presented in Figures 4 and 5, that the majority of the leaching took place in the first hour in weathered spoil, but was delayed in unweathered spoil. The weathered spoil also produced less leachable salts to the solution. These experiments were steady state mixtures of 12.5 grams of spoil in contact with 172.5 ml of distilled water (i.e., 10% spoil). The spoil sample designated D-3 is concluded to have produced 8.5 kg of dissolved solids per cubic meter during the test. Other samples produced the amounts of dissolved solids shown in Table 5.

SUMMARY

In conclusion, both surface and underground coal mining activities have a high potential to impact the quantity and quality of both local and regional ground water systems. Such impacts may be short-term and/or longterm in duration. As identified in this paper, the local hydrogeologic system plays the principal role in the extent of quantity - related imports to the ground water system. Ground water quality effects as they relate to coal mining activities are primarily related to the chemical characteristics of the local geologic system.

Table 5

Soluble Salts in Spoil

	kg/m^3
C-1	0.84
C-2	1.10
C-3	1.89
D-1	2.73
D-2	3.14
D-3	8.50
D-4	4.29

(from Pagenkopf et.al., page 118)

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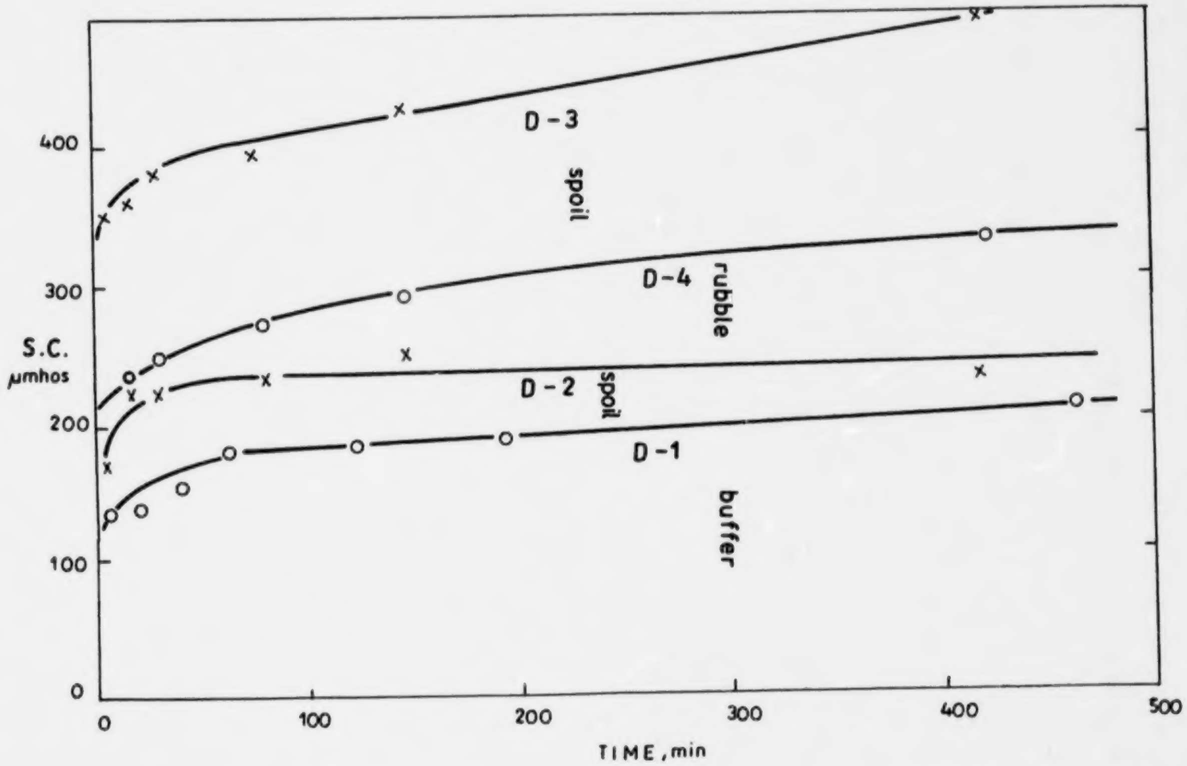

Fig.5. LEACHING OF DECKER SPOIL WITH TIME, 10% SOLUTION, D-1, D-2, D-3, D-4 DESIGNATE THE PARTICULAR SPOIL.

PAGENKOPF ET. AL.

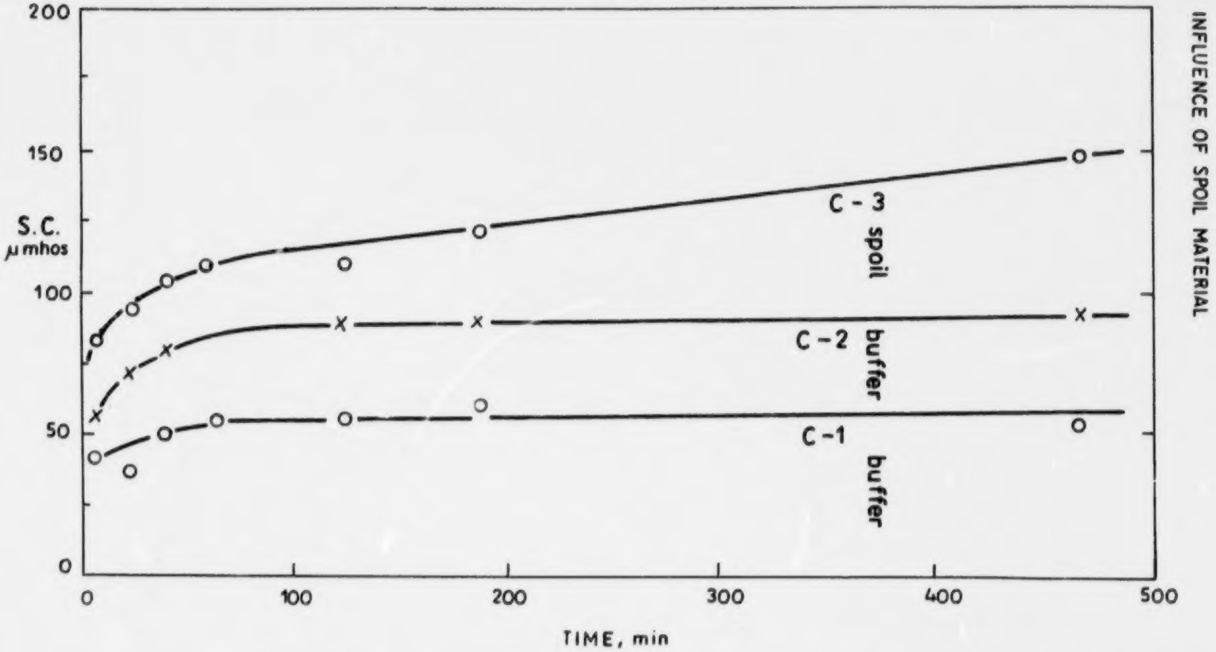

Fig. 4. LEACHING OF COLSTRIP SPOIL WITH TIME, 10% SOLUTION, C-1, C-2, C-3 DESIGNATE THE PARTICULAR SPOIL.

PAGENKOPF ET. AL.

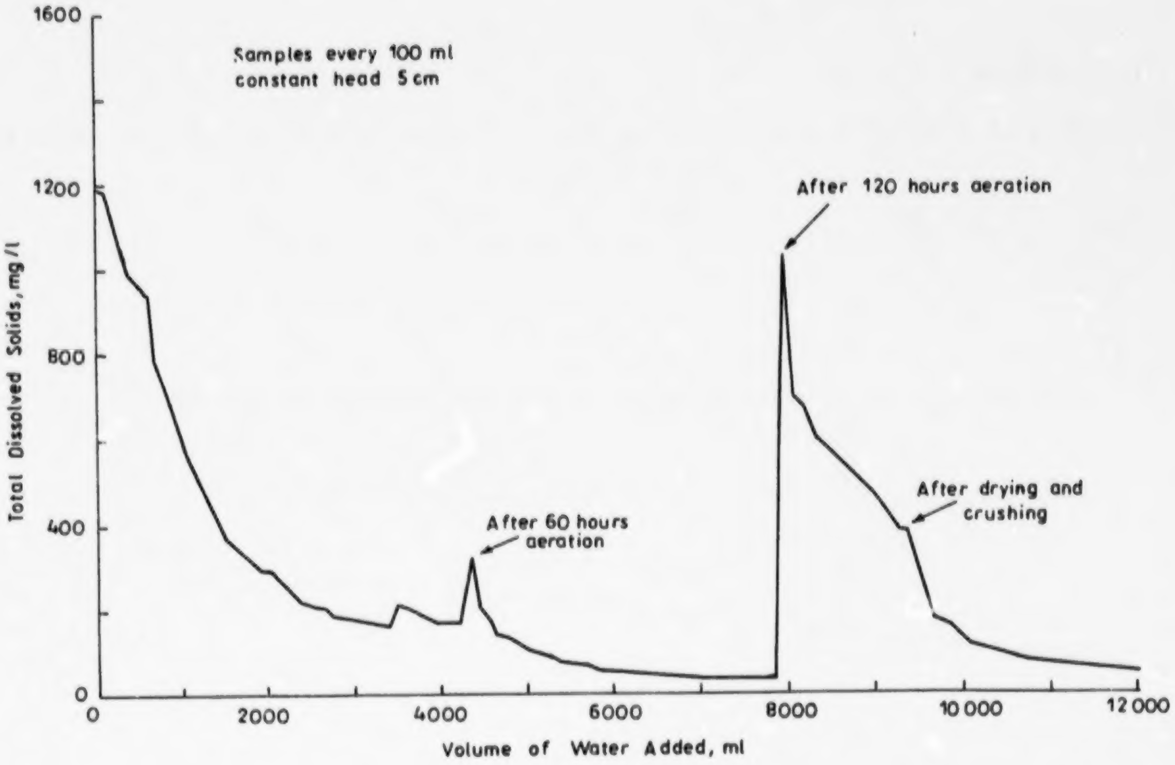

Fig. 3 RESULTS OF LEACHING TEST WITH AERATION OF SAMPLE TO PRODUCE WEATHERING. AFTER McWHORTER ET. AL.

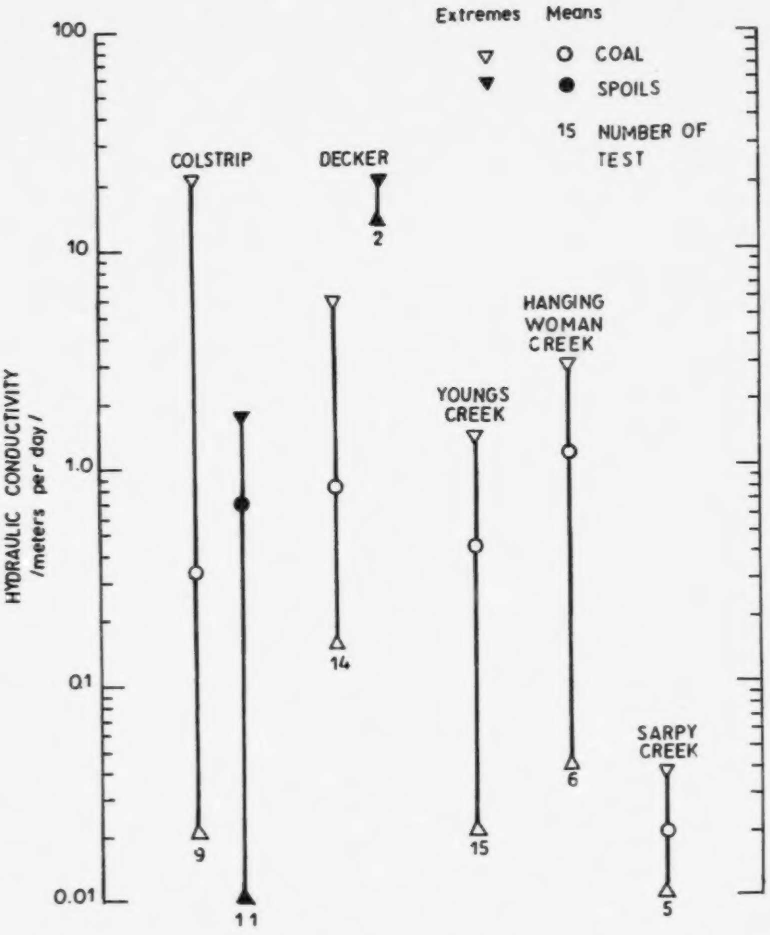

Fig. 2 HYDRAULIC - CONDUCTIVITY RANGES AND MEANS FOR COAL AND MINE SPOILS IN SOUTHEASTERN MONTANA. AFTER VAN VOAST.

IMPACT OF SURFACE MINING AND CONVERSION OF COAL ON GROUND WATER AND CONTROL MEASURES IN POLAND

by

Jacek Libicki[x/]

INTRODUCTION

Current trends in energy development in Poland and in the United States - and practically throughout the world - point to coal as a fundamental power source for the next twenty years. In many countries the surface mining of coal contunually gains the advantage over underground mining. This is attributable to better work conditions, larger mechanization possibilities and lower exploitation costs of an openpit mine. Surface mining, however, exerts an undesirable effect on the environment in general, and ground water in particular. The impact of coal surface mining on the ground water should be considered in both quantitative and qualitative categories. The mining operation conducted below the ground water table requires a drawdown of the water table. This drawdown is caused both by the mine itself and by the draining systems. Such depression of the water table, is not limited to the mine area only; dependently on hydrogeological conditions it may extend for a number of kilometers outwards from the center of work. Therefore, regardless of the draining system (the pit itself, the system of wells or galleries) natual hydrogeological conditions are disturbed quantitatively. Quality of the ground water independently of the used drainage system remain unchanged.

[x/] Dr. Jacek Libicki, Chief Geologist, POLTEGOR, Rosenbergów 25, Wrocław

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The mine drainage in general, and the adopted method of its performance in particular, affects the quality of the water offtaken from the mines. This problem is a subject of a separate report. Thus the ground water is not as much affected by the mining operation itself as by considerable amounts of wastes and ashes due to the coal conversion processes which are very often stored in old open pits.

Thus coal mining affects the ground water quantity and quality.

QUANTITATIVE IMPACT

The horizontal and vertical range of the ground water table drawdown, due to mining operation, is a function of many factors. The most important are:

- depth of the depression in the center of drainage
- structual elements of the spatial geological structure of the entire region
- permeability parameters (filtration coefficients and specific yield)
- time.

Weight of the problem induced the relevant Polish regulations to require investigations on the possible effect of coal mining on the hydrogeological conditions of the exploitated area, already at the stage of the geological deposit recognition. Therefore plans of geological investigations of coal deposits must not be limited only to the assigned for the exploitation deposits, but consider also the adjoining lands. Basic elements of these studies are the bore holes, made in rectangular pattern or radial lines starting at the center of exploited area (i.e. from the place with the greatest anticipated water table drawdown). The number of lines most often varies from 4 to 8. Concentration of these bore holes is greater near the center (most frequently about 0,5 km) and smaller far from it (most frequently one to three km and depends on the distance from the center). Length of these radial lines depends on the preliminary forcasted range of the depression cone which in the Polish mines oscillates from 5 to 15 km, what is the value 50 to 100 times greater than the water draw-down in the center of the drainage. Such bore holes serve to determine geological structure of the region, thickness of the particular aquifers and links between them, and also to determine filtration parameters of aquifers, situation of the water table and its changes in time (Fig. 1). Many of these bore holes are provided with filters and hermetically locked. They can be used later as monitoring wells for the periodic control of the changes in the ground water table, due to the mine exploitation.

Results of the mentioned above investigations together with the results of the other investigations are specified in the Official Geological Report which must be presented to the official approval by the Central Geological Administration, and are the basis for mine design.

Mine construction design must, include the forcast of mining impact on the ground water at this area and also the appropriate control methods. These design have to be approved by the local authorities. (Fig. 2).

A forecast of the depression cone development in time has to be prepared in aim to evaluate probable damages due to the ground water table drawdown. Various methods can be used according to the geological structure of the considered area and to the required degree of the results accuracy (1). Recently the mathematical modelling method for computer simulation has been introduced (Fig. 3). The model is based on the Boussinesque non-linear equation and includes three dimensional variation of anisotropy of permeability and the precipitation infiltration (2). Program consists of the BEŁCHATÓW initial data basis. The subprogram WODA, written in FORTRAN 1900 language with operating verses for the XFAM translator, performs the conversion of the initial data entered in square pattern to a quasi-radial system. It is followed by the necessary rendering average of filtration coefficients and of specific yield in particular sectors, performed by the WODA 1 sub-program, also written in FORTRAN. This sub-program prints the results for each radial sector in a separate verse. The following subprogram WODA 2, computes the range and shape of the depression cone and water inflow to the mine in each sector for the steady flow condititions. This subprogram is also written in FORTRAN. The subprogram WODA 3 computes the filtration curves in the nonsteady flow for the optional time step and considers only those initial data in each sector, which for a given time step are within the depression cone range.

At present this program is being tested in practice in the Bełchatów mine.

The deep drawdown of the ground water table affects not only the agriculture, forests and water supply (1), but changes the entire hydrological balance in the region (Fig. 4). Investigations based on the equation of the developed hydrological balance in the aeration zone and the hydrogeological balance have indicated (3) that within the range of the deppression cone (effected by mine draining operation) occur changes presented by the table no. 1.

The table no. 1 indicates that within the range of the depression cone the surface run-off decreases by about 30 percent, ground water evaporation by 100 percent, evaporation from the land surface by about 15 percent while infiltration of precipitation increases by 70 percent, and the underground runoff by about 100 percent.

Great economic and environmental significance of the discussed phenomena requires not only forecasting but current control as well. For this purpose a network of piezometers (consisted of prospection holes provided with filters and the currently executed special holes, together with network of the existing wells) is built around the mine. Regular measurements of the ground water table are carried out in all those piezometers as often as once or twice a month. These measurements are so far carried out manually, but introduction of remote sensing methods is planned for the future. Obtained data are used to check the forecasts and to plan the damage removal in the following periods of time. The last problem has been solved so far by the changes of cultivation structure and construction of new water supply systems (1). These are only defensive methods, and therefore not the best. More active methods based on the construction of tight screens around mines which on one hand would stop the inflow of water into the mine, and on

Natural and enforced hydrological balance in the Widawka river basin (mm)

Table no. 1

Type of soil cover	Kind of balance	Precipitation	Infiltration of the precipitation	Underground runoff	Groundwater evaporation	Superficial runoff	Superficial evaporation
		P	$W = H_g + E_s$	H_g	E_s	H_p	E_a
Sands	natural	615	223	144	79	65	327
	enforced by dewatering	615	359	359	0	42	214
	diferences	0	+136	+216	-79	-23	-113
Clays	natural	615	68	48	20	65	482
	enforced by dewatering	615	91	71	20	42	482
	differences	0	+23	+23	0	-23	0

the other hand could limit the depression cone development would be developed in future (4). Such methods although technically possible are not used in practice due to high costs of their construction. The future however may change such point of view, when prices of water and agriculturally rich lands will raise, as it is now in the case of fuels.

QUALITATIVE IMPACT

As it has been said already, the influence of coal surface mining on ground water quality is indirect and is due mainly to the storage of coal conversion and treatment wastes in old openpits. This problem has been neglected for a long time. Increasing of environmental requirements induced investigations on that problem. The first large project in this field was the project (4) realized by POLTEGOR (and sponsored by US EPA) having in goal:

- to determine qualitatively and quantitatively the impact of coal refuse and ashes storage on the ground water quality
- to determine spatial and temporal interrelations of pollutants' propagation
- to suggest some improved methods of storage
- to prepare recommendations for tests, prognoses, and for control systems.

A research plan has been prepared with regard to the actual state of art and technological and financial possibilities. This plan was based on:

- field investigations on two test disposals of wastes
- laboratory analyses of water and wastes
- model tests of the selected aspects of pollutants' migration.

For the realization of this program two waste disposals have been built.

Disposal No. 1 - has a length of about 40 m, width 20 m, thickness about 2 m, and volume about 1500 m^3. It was located at the bottom of a stowing sand open-pit, with a layer of sand 1,5 to 2 m thick and filtration coefficient about 50 m/24 hours. The ground water table was a few centimeters below the sand surface, i.e. just under the floor of the disposal.

The stored material consisted in 70 percent of coal refuse, and in 30 percent of ashes from the coal fired power plants.

Within this disposal and in its immediate vicinity 12 monitoring wells, have been constructed. During the period of 15 months water was sampled from these wells for chemical and physical analyses every 3 weeks. Measurements of the water table level were simultaneously carried out. Then these tests were continued at 6 weeks and 3 months time intervals. Each time a comparative sample of "pure" groundwater was taken before its entering the zone of disposal influence in a point situated up the ground water stream. Prior to taking samples water was being scouped from each well in the quantity of the well double volume. Simultaneously in the nearby hydro-meteorological station observations of average air temperature and of local precipitation were carried out. This was that much important as the disposal was being washed by the rain water, leaching and carrying away pollutants.

Apart from the mentioned analyses, the wastes have been leached in laboratory filtration columns at optimum inflow conditions, with the object to obtain maximum possible concentrations of particular compopollutants.

All water samples have been physico-chemically analysed to obtain 17 determinations, and every third series to obtain 45 designations together with heavy metals.

First small symptoms of pollution have been found in the immediate subsoil of the disposal after one month of storage. The main amount of pollutants hasbeen found downstream of the ground water after a heavy rains period i.e. about 7 months after storage.

Maximum content rise in ground water as follows:

sodium	from	3.0	to	500 mg/l
chlorides	from	10.0	to	400 mg/l
potassium	from	2.0	to	40 mg/l
magnesium	from	10.0	to	30 mg/l
sulphates	from	100.0	to	900 mg/l
phosphates	from	0.05	to	0.3 mg/l
boron	from	0.2	to	2.0 mg/l
molybdenum	from	0.005	to	1.0 mg/l
copper	from	0.003	to	0.2 mg/l
strontium	from	0.07	to	0.4 mg/l
cadmium	from	0.002	to	0.005 mg/l
cyanides	from	0.002	to	0.008 mg/l

No increase, however, was observed in the content of iron, manganese, aluminium and chromium. Increase in content of zinc, mercury and lead was doubtful.

Comparing the pollution levels with the requirements of Polish Drinking Water Standards one can notice, that the greatest hazard were sulphates which concentration in the water (affected by the disposal) exceeded 4 - times the admissible values for the third class, total dissolved substances exceeded by 100 percent, chlorides by 150 percent, boron by 100 percent. In general, during the last 2 $^{1}/2$ years' 11.500 kg of pollutants i.e. 0.7 percent of its total volume, and about 70 percent its all soluble substances have been washed out from the 1500 m^3 disposal.

The main bulk of the pollutants (90 percent) has been washed out in the direction of the greatest downgrade of the ground water table, and only 10 percent in the directions of smaller gradients of water table.

Disposal No. 2

An old open-pit of stowing sand in Boguszowice (with disposal volume 1 million m^3) has been used as a second test disposal. The storage of wastes, mainly of coal wastes in amounts 20-40.000 m^3/month in this pit began in 1975. Fourteen monitoring wells were constructed around the disposal at the distances of 100-1000 m to control hydrogeological conditions and water quality.

Investigations carried out as in the disposal No. 1 enabled to find out that during the first 2 years of observations, despite of the similar pollution potential, less pollutants passed to the ground water. In the third year the considerable amounts of pollutants were found in disposal vicinity. Interpretation of results has not been concluded yet.

MODEL TESTS

Investigations carried out on soil models and on analogous models showed that:

- within the limits of 2 percent difference between the polluted water and pure water density no vertical migration of the polluted water has been found below the disposal,
- the main migration takes place in the zone close to the ground water table and in the zone of capillary rise; this tendency is the greater the smaller are doses of pollutants,
- if the disposal has smaller permeability than the surrounding aquifer the stream of pollutants leaving the disposal has a tendency to get thinner,
- local depression of the aquifer floor increases thickness of the pollution stream, while local elevations cause the local thickness reduction.

The tests on AEHD model enable to reproduce hydrodynamic network and migrations velocity quite accurately but give poorer results in predicting of particular components' concentrations.

SUMMARY

All tests allowed to make recommendations in the following groups of problems:

I - Classification of the wastes

- mine wastes: dry wastes and wet wastes (from flotation, from water medium washer and heavy medium washer)
- power plant wastes: ashes and slags (fly ash and bottom ash).

Each group has different physical and chemical properties which cause their different behaviour on disposals.

II - Methods of laboratory analyses of wastes for preliminary evaluation of their impacts on ground water.

Investigation methods recommended before and during the storage have been, distinguished here with regard also to time and to the importance of the problem for water management in the region.

III - Classification and evaluation of disposals

1. With regard to spatial relations, between the disposal and aquifer
   A. Dry disposals - above ground water table
      a) impermeable
      b) permeable
   B. Wet disposals - below ground water table
      a) impermeable
      b) floor impermeable, slopes permeable
      c) floor permeable, slopes impermeable
      d) floor and slopes permeable.
2. With regard to the disposal permeability in relation to the aquifer.
3. With regard to the protection requirements of the entire aquifer of ground water or its part.

4. With regard to the mutual situation of the disposal and the protected element.

5. With regard to the degree of ground water protection
   a) total
   b) partial (certain parameters of their values).

IV - Planning and designing of disposals.

The formulated here recommendations refer to the scope and methods of hydrogeological investigations (requirred before the storage), to the initial data for the planned utilization of ground water in the considered region, to the stipulations of local authorities, to the actual quality of the ground water, to forecasting methods, to the possibility of storage in the determined hydrogeological conditions and to the methods of preventing aquifiers from the pollution migration.

V - Designing of monitoring systems and control work.

Recommendations referring to the situation of monitoring wells, to the technology of their execution, to the frequency and methods of water sampling and to the interpretations of results have been given.

VI - Directions of further studies for the ultimate solution of the problem.

CONCLUSIONS

1. The surface mining may often cause lowering of the ground water table, and in effect could form a widely developed depression cone. It can also change hydrological balance of the region and cause the necessity to change cultivation profile and to build substitute water intakes.

2. Storage of coal refuse and ashes in open pits substantially affects the ground water quality.

3. Prior to planning of mines and disposals' siting, investigations and prognoses should predict the scope of possible changes in the ground water.

4. More effective methods of protection the ground waters from the effects of mining industry should be introduced instead of solving already existing disturbances in this field.

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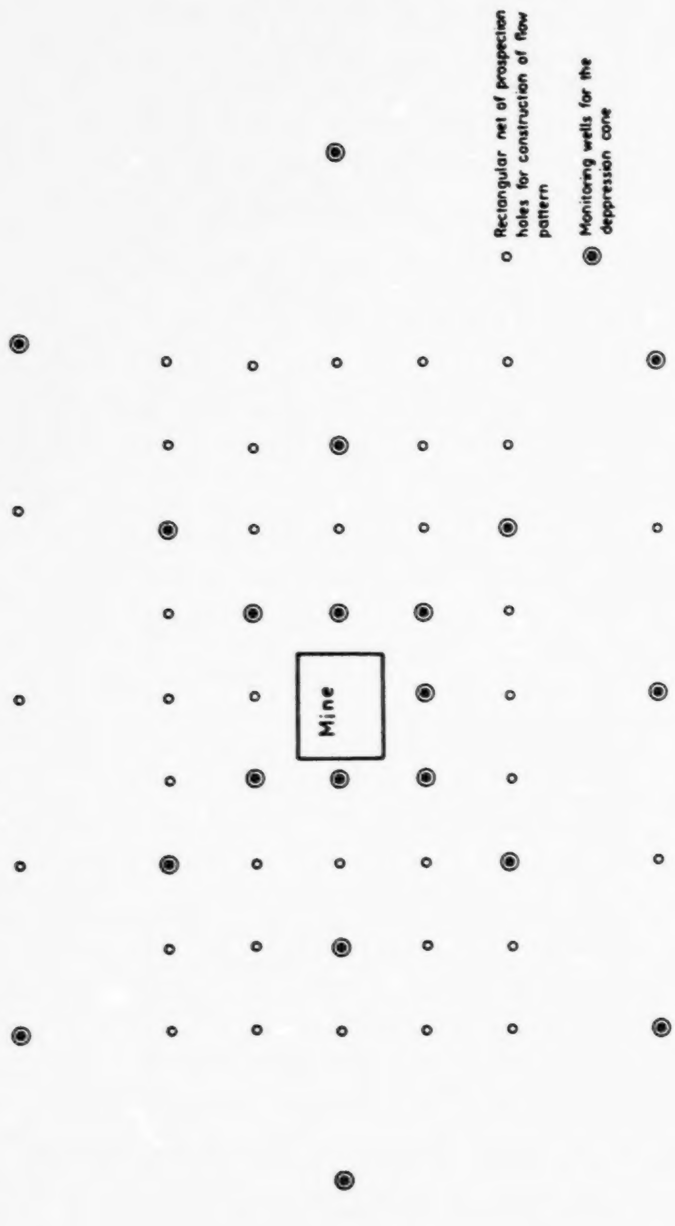
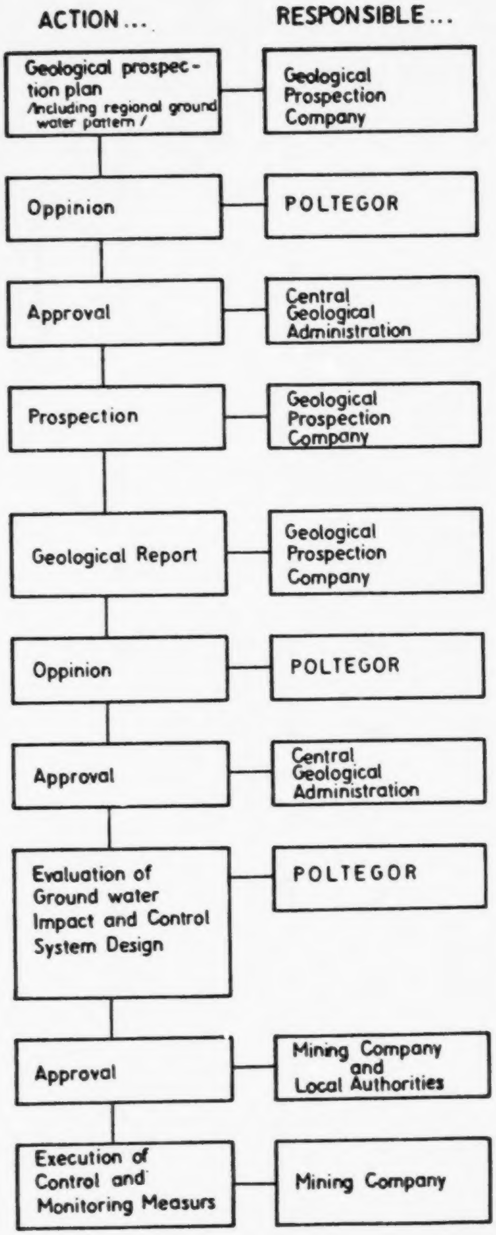

Mine
○ Rectangular net of prospection holes for construction of flow pattern
◉ Monitoring wells for the deppression cone

Fig.1 Scheme of Investigation and Monitoring of Cone Deppression Development


ACTION...
RESPONSIBLE...
Geological prospection plan /Including regional ground water pattern /
Geological Prospection Company
Oppinion
POLTEGOR
Approval
Central Geological Administration
Prospection
Geological Prospection Company
Geological Report
Geological Prospection Company
Oppinion
POLTEGOR
Approval
Central Geological Administration
Evaluation of Ground water Impact and Control System Design
POLTEGOR
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Mining Company and Local Authorities
Execution of Control and Monitoring Measurs
Mining Company

Fig.2 SEQUENCE OF ACTIONS FOR GROUND WATER CONTROL IN MINING REGIONS.

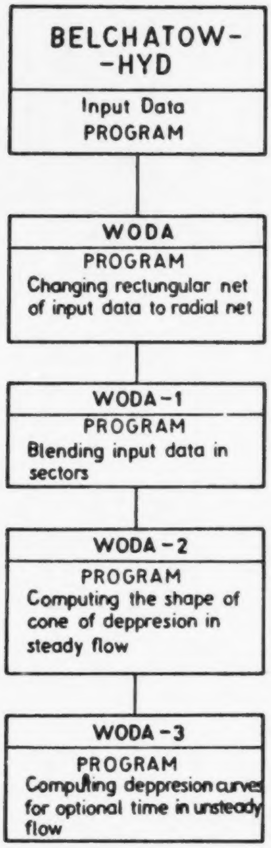
BELCHATOW-
-HYD
Input Data
PROGRAM
WODA
PROGRAM
Changing rectungular net of input data to radial net
WODA-1
PROGRAM
Blending input data in sectors
WODA-2
PROGRAM
Computing the shape of cone of deppresion in steady flow
WODA-3
PROGRAM
Computing deppresion curves for optional time in unsteady flow

Fig. 3 SCHEME OF MATHEMATICAL MODELL COMPUTING THE CONE OF DEPRESSION DEVELOPMENT /PROGRAMS IN FORTRAN 1900 LANGUAGE/

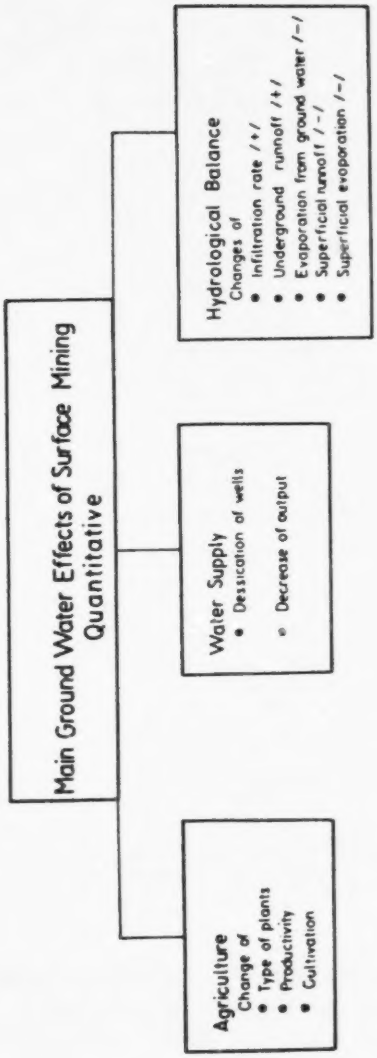
Main Ground Water Effects of Surface Mining
Quantitative
Agriculture
Change of
• Type of plants
• Productivity
• Cultivation
Water Supply
• Dessication of wells
• Decrease of output
Hydrological Balance
Changes of
• Infiltration rate /+/
• Underground runoff /+/
• Evaporation from ground water /−/
• Superficial runoff /−/
• Superficial evaporation /−/

Fig. 4

THE IMPACTS OF COAL MINING ON SURFACE WATER AND CONTROL MEASURES THEREFORE

by

Ronald D. Hill x/

INTRODUCTION

During 1971, coal provided 19 percent of the 68,975 trillion BTU's of energy consumed. Seventeen percent of the projected 1985 demand of 133,396 trillion BTU's is to be supplied by coal. In 1972 an estimated 582 million tons of coal were consumed. The forecasted coal production in 1985 is 1,088 million tons of which 245 million tons will be used to make synthetic gas.(1) These figures indicate the important role that coal plays in the energy picture.

Two important trends are occurring, i.e., increased surface mining and Western mining. In 1972 for the first time, surface mining produced over half the coal. Surface mining will probably hold this position in the near future. With the above projected increase in demand, the amount of land disturbed each year will nearly double by 1985.

Another trend is the shift to western coals. Approximately 60 percent of the coal mined in 1970, mostly eastern coals, will not meet the EPA air quality standards. (1) The low sulfur content of the western coal and improved coal prices has offset the high transportation cost. Mine mouth power plants and coal gasification are projected added

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x/ Ronald D. Hill - Director, Resource Extraction and Handling Division, Industrial Environmental Research Laboratory - Cincinnati U.S. Environmental Protection Agency Cincinnati, Ohio 45268.

incentives to utilizing western coal. Peabody Coal Company estimated that by 1980 the states of Montana and Wyoming will rank with the top five states in surface mining. Arizona, Colorado, Utah and New Mexico will also be up in the rankings. (2)

WATER PROBLEMS ASSOCIATED WITH COAL MINING

Acid Mine Drainage

One of the most troublesome mine drainage problems is caused by acidity. Although the exact mechanism of acid mine drainage formation is not fully understood, it is generally belived that pyrite (FeS_2) is oxidized by oxygen (equaticn 1) or ferric iron (equation 2) to produce ferrous sulfated and sulfuric acid. (4)

$$2FeS_2 + 2H_20 + 70_2 \longrightarrow 2FeSO_4 + 2H_2S0_4 \tag{1}$$

$$\text{(Pyrite)} \longrightarrow \text{(Ferrous Iron)} + \text{(Sulfuric Acid)}$$

$$FeS + 14Fe + 8H_20 \longrightarrow 15Fe + 2S0_4^{2-} + 16H \tag{2}$$

$$\text{(Pyrite)} + \text{(Ferric Iron)} \quad \text{(Ferrous Iron)} + \text{(Sulfate)} \quad \text{(Acid)}$$

The reactions may proceed to form ferric hydroxide and more acid:

$$4FeS0_1 + 20_2 + 2H_2S0_4 \longrightarrow 2Fe_2(S0_4)_3 + 2H_20 \tag{3}$$

$$Fe_2(S0_4)_3 + 6H_20 \longrightarrow 2Fe(0H)_3 + 3H_2S0_4 \tag{4}$$

A low pH water is produced (pH 2-4.5). At these pH levels, the heavy metals such as iron, calcium, magnesium, manganese, copper and zinc, are more soluble and enter into the solution to further pollute the water. Water of this type supports only limited water flora, such as acid-tolerant molds and algae; it will not support fish life, destroys and corrodes metal piers, culverts, barges, etc., increases the cost of water treatment for power plants and municipal water supplies, and leaves the water unacceptable for recreational uses.

As estimated 10,000 miles of streams have been degraded in Appalachia alone. (3) Additional acid problems in Western Kentucky, Indiana, Illinois, and Montana have been documented. (4,5,6,7).

Alkaline Mine Drainage

Alkaline mine drainage may result where no acid-producing material is associated with the mineral seam or where insitu neutralization of that acid which is produced has taken place. Alkaline mine drainage may be, but is not usually, as bad as acid mine drainage. Drainage from freshly exposed strata usually has a higher mineral content than that from undisturbed land because the strata has high levels of readily leachable materials.

Some alkaline waters have high concentrations of ferrous iron and upon oxidation and hydrolysis, form acid which lowers the pH and changes the drainage to the acid type. These types of discharges are more common to underground mines than surface mines.

The Western mines present new problems. In many areas the overburden material is highly alkaline and sometimes saline. (8). Improper handling of this material can lead to pollution of surface water, stock-watering ponds and maybe even groundwater.

Documentation of the alkaline and saline problem is almost none existent.

Sedimentation and Erosion

The removal of the vegetation and the loosening and breaking up of the overburden by blasting, shovels, draglines, and dozers creates materials and conditions conductive to erosion. Curtis (9) and Collier, et al, (10) have documented the increased sediment and suspended solid loads from surface mined areas.

Sediment fills creek beds destroying fish habitat and creating flooding conditions. Suspended solids increase treatment cost for industrial and municipal supplies.

Erosion is influenced by the soil type, (sand, clay, salt, infiltration rate and percolation rate), the climate (temperature and amount and type of rainfall), the topography (steepness, length of slope, land configuration and exposure), and the vegetation cover. Each of these factors should be considered in the planning, development and reclamation of a surface mine to prevent erosion.

SOURCES OF MINE DRAINAGE

Surface mines

Surface mines fall into two broad types: area and contour. Area surface mining is practiced on relatively flat terrain and usually encompasses a large tract of land, up to several hundred or more acres. It can be found mainly in Ohio, Western Kentucky, Illinois, Indiana, and west of the Mississippi River. Contour mining is practiced on rolling to very steep terrain. Usually only a few cuts are made into the hillside and the coal seam is followed along the edge of the hill or mountain, leaving a trace which appears as a "contour line".

In general, the pollution from area mines is not as severe as that from contour mines. Overburden can more easily be segregated during mining and the acid producing or saline material buried. Silt from erosion can often be confined to the mining area. The overburden can be graded to a slope that is less erosive. Final cuts can be filled with water to prevent oxidation of the pyrite material. Areas that have been area mined have been shown to have lower peak flows and increased base flows. (4,11)

The common practice in the past was the placement of the overburden from a contour mine onto the downslope of the adjacent area. This material was subject to severe erosion and landslides. Plass (12) made a survey of eastern Kentucky and found that 12 percent of the outslope area had failed (landslides). Because of the landslide problem, West Virginia has limited the bench width on steep slopes greater than 65 percent. (17). Even with these precautions, landslides still occur.

Many water problems arise from this type of mining. The highwalls and spoil piles, because of their long, bare, steep, uninterrupted slopes are subject to severe erosion. Sediment coming off these slopes has been known to clog stream channels, cover highways, settle on cultivated land and kill crops, cover fish spawning beds, fill water courses, and thus, subject adjacent land to flooding, etc.

A study of water sheds draining to Beaver Creek, Kentucky, (9), (13) showed that a partially stripped watershed (6.4 percent of area) had an average erosion rate of 5.9 tons per acre per year as compared to 0.7 tons per acre per year for an unmined area.

Curtis (14) has found that contour mines in Kentucky in non-acid areas still cause changes in water quality in the adjacent streams. Among the elements showing greatest increase are sulfate, calcium and magnesium. Aluminum, manganese, iron and zinc also increase some. In general the increase did not reach a serious magnitude.

Even when spoil piles are graded, problems, occur. If the grading is toward the highwall, the water may accumulate in an area of poor quality spoil, (i.e., a spoil high in pyritic material) and may therefore be degraded in quality. Where underground mines are located behind the highwalls, grading toward it often causes water to flow into the underground mine. This flow often flushes toxic material from the mine.

When spoil piles are graded away from the highwall, erosion may be as bad or worse, unless good water management practices are followed, such as diversion ditches across the top of the highwall, ditches or terraces across the slope to break the slope length and control structures to remove the water from the mining area.

Underground Mines

During the period when an underground mine is active, water must be removed either by gravity or by pumpage. The characteristics of this water will vary from seam to seam and even within the same mine. Following active mining, below drainage mines usually fill with water and are often no longer a source of pollution. However, those above drainage continue to discharge polluted water for decades.

The Appalachian Study (3) reported that active underground mines produced 18.8 percent of the acid mine drainage and inactive underground mines 52.5 percent. An additional 9.2. percent came from a combination surface-underground. Thus, underground mines were involved with 80.5 percent of the acid mine drainage.

Siltation is not usually associated with underground mines, however, the waste "gob" removed and piled outside the mine is a major source of silt, acid mine drainage and often air pollution from ignition.

Whereas control technology for surface mines is highly developed, the technology for underground mines is severely limited.

Refuse Piles and Slurry Ponds

Associated with many coal mines is a cleaning or processing plant where the coal is processed to remove dirt and impurities present in the coal. Two types of wastes are discharged from a cleaning plant - refuse and slurry. The refuse is the coarse portion consisting largely of coal intermixed with pyrites, sandstones, clays and shale. Refuse has historically been piled adjacent to the cleaning plant and has created major silt and acid water pollution problems and air pollution. Slurry is the fine reject material which contains mostly coal, shale and clay. The slurry is usually placed in lagoons adjacent to the plant. Slurry can create major sediment problems in streams when it is discharged directly to the stream or escapes from lagoons because of poor design, construction or maintenance. Upon abandonment, slurry lagoons continue to be a menace unless they are stabilized. Often slurry ponds are not acid.

CONTROL OF MINE DRAINAGE

Acid Problems

The ultimate solution to the acid mine drainage problem is preventing its formation. As noted in equations 1 through 4, the reaction is dependent on air (oxygen) and water coming in contact with the sulfides. In addition to water being a reactant, it serves as the transport media for the metals. All prevention techniques are based on excluding water and/or air from the mining environment.

Air: Air is necessary during the active operation of an underground mine. After the coal has been extracted, excluding air should be an integral part of the mining plan. As areas are worked out, blockages should be made to prevent air from entering that section of the mine. Mines should be developed downdip so that they flood when abandoned. In this manner, water serves as an oxygen barrier. Injecting solid material into the mine, such as stope filling, should be encouraged and expanded. Not only can the mine drainage problem be decreased by blocking the flow of air, but a solid waste disposal problem can be resolved simultaneously.

Sealing adits to prevent air from entering an underground mine has been in practice in the coal fields since the 1920's. This procedure at its best, has only been marginal. Seals can be built to orevent air from entering the adit, but air reaches the mine readily through the fractured outcropping and overburden. With each change in barometric pressure, air is pumped in and out of the mine. Air sealing should not be considered as an acceptable method.

Bulkhead or hydraulic mine seals have been shown to be successful. (15) For this method, a seal is built in the adit and the outcrops is grouted to prevent water from leaving the mine. In time, the mine workings are flooded and oxygen is excluded from the sulfides.

Excluding oxygen from the active surface mine is not feasible. Usually there is a delay between the time the sulfides are exposed to air and acid mine drainage is formed. High sulfide bearing material should be exposed for the shortest time possible. As part of the mining operation, this material should be covered with material containing little or no sulfides. The saving and replacement of top soil should be practiced. The cover material acts as an oxygen barrier. Wind and diffusion are the only driving forces for moving air through the cover material to the sulfides. The cover material should be vegetated with grasses, legumes, shrubs, forbs, etc. Not only does the vegetation serve to stabilize the cover material and prevent it from eroding, but upon dying, it decays and acts as an oxygen absorber.

Refuse dumps at mines are major sources of mine drainage and should be constructed to prevent air movement into them. Sound techniques are compacting waste material as it is placed and sandwiching layers of compacted clay between layers of waste. The slopes of the dumps should be kept to 33 percent or less to prevent wind from driving air into the pile. Upon abandonment, the surface of the pile should be sealed with an air barrier. Although many different materials have been evaluated, soil still remains the best. As in the case of surface mines, the surface should be vegetated.

Water: Enough water is usually available in the moist air within an underground mine or within the material itself in a surface mine or waste dump to meet the requirement for the formation of mine drainage. The other function of water is as a transport media. If flushes the oxidation products from the sulfide and carries them into the environment. By controlling the water, these products can be contained.

Provisions should be made to prevent water from entering the mining environment, except where it is to be used for flooding and an oxygen barrier. Diversion ditches, dewatering of the working and sealing of fractures are just a few of the methods available. Water that does enter the workings should be removed as rapidly as possible.

Silt Problems

The control of silt from surface mines starts in the mine planning stage and follows through mining and final reclamation. During the planning state, water handling throughout the operation should be carefully planned. This stage includes the location of diversion ditches to keep water out of the mine working, protection of natural drainageways, location of silt traps and basins, and the selection of a mining method to minimize erosion and landslides. The Statesof Kentucky (16) and West Virginia (17) have developed drainage handbooks as guidelines. In recent years several new mining methods such as slope reduction, box cut and block cut have been developed to reduce silt and slides. (18), (19) The removal, storage and replacement of topsoil are other valuable tools in erosion control. Backfilling and planting should follow mining closely to minimize the period that bare materials is exposed. Grading should be planned to keep slope length and steepness to a minimum. Terraces and benches should be included to reduce runoff rate. Final grading should be across the slope.

Grasses should be planted on all areas fro rapid erosion control. Trees may follow if needed or desired. Before planting, soil analysis should be made and the proper fertilizer and lime added. On steeper slopes mulches may be needed.

In some cases the silt basins may not be capable of reducing the sediment load to an acceptable level because of the colloidal nature of the material. The addition of lime, alum and other flocculating chemicals might be required in conjunction with the silt basin.

Treatment

Treatment has three places in the acid mine drainage scheme: (1) during active operations to produce a water acceptable for discharge to a stream, (2) in those situations where the production of acid mine drainage cannot be prevented and (3) in those cases where water is needed for industrial or domestic use.

Neutralization

The most commonly used method for treating acid mine drainage and removing heavy metals is neutralization. A typical system would include adding an alkaline reagent, mixing, aerating, and removing the precipitate. Alkaline reagents that may be used are ammonia, sodium carbonate, sodium hydroxide, limestone, and lime. In most cases, lime is used because of its lower cost and higher reactivity.

Most heavy metals tend to precipitate as the pH is raides. Metals such as copper, zinc, iron, aluminum, manganese, nickel and cobalt can be reduced to low levels, less than half mg/l, with pH adjustment, precipitation and solids separation.

In removing iron, aeration is used to convert the ferrous from to the ferric form to take advantage of the precipitation of ferric iron at a lower pH.

In most cases, lime is used for neutralizing. Except for limestone, it is the cheapest reagent, and also reacts rapidly. The disadyantage is the voluminous sludge produced. Although limestone is cheaper and produces a denser sludge, it is not effective above a pH of 6.5 because of the slow attack of limestone by acidity at higher pH's. Two - stage treatment with limestone followed by lime appears to offer the advantages of both reagents. EPA has studied its use on coal acid mine drainage. (20)

Although neutralization can be used to remove heavy metals and a portion of the sulfate, the resulting water is high in dissolved solids and sulfate. The disposal of the sludge is also a problem.

Ion Exchange

Various ion exchange schemes had been applied to the treatment of coal acid mine drainage. (10) These schemes can upgrade the water quality to potable use. Modification can be incorporated to recover heavy metals. Ion exchange has not received wide acceptance because of difficulties encountered with resin fouling, interfering ions, limited loeading capacity, cost of operating and disposal of regenerating solutions. Further development is needed.

Reverse Osmosis

Reverse osmosis (R.O.) has effectively removed multivalent ions from mine drainage. Table I presents data from the treatment of coal mine drainage. All heavy metals should be removed at about this same level (99 percent or better). Reverse osmosis is a concentrating process in which the pollutants are contained on one side of a membrane while the water passes through. Water recoveries (percent of water fed to unit that is available as treated water) have been as high as 90 percent. Water recovery is limited by the precipitation of material on the membrane when they have been concentrated beyond the materials saturation point. Calcium sulfate is usually the first material to be precipitated in mine drainage. Equations have been developed to predict the highest water recovery allowable under any influent condition. (22,23)

Since R.O. is a concentrating system, the disposal of the waste stream is a major problem. EPA has developed a system whereby the waste stream is neutralized, the sludge removed, and the neutralized water returned to the influent of the R.O. unit. This system has been named "Neutrolosis" and has obtained water recoveries in excess of 99 percent.

TABLE I

TREATMENT OF MINE DRAINAGE BY REVERSE OSMOSIS

	Removal - Percent
Ca	98 - 99.8
Mg	98.5 - 99.8
Fe, Total	98.5 - 99.9
Al	91.7 - 99.2
Mn	97.8 - 99.1
Cu	98.7 - 99.5
SO_4	99.3 - 99.9
Acidity	81.0 - 91.7
Specific Conductance	95.0 - 99.9

SUMMARY

Coal will continue to provide a significant amount of the energy of this country. The very concept of disturbing the earth to remove any material, whether by surface or underground methods will cause changes in the environment. We must strive to make these changes create a minimum of temporary or long- term damages.

With our present technology, most acid mine drainage problems can be controlled during active mining and upon abandonment of surface mines and refuse piles. This statement cannot be made of underground mines. In the majority of cases, acid mine drainage cannot be controlled from abandoned or orphaned underground mines.

We are still short on technology for controlling silt and landslides from surface mines. Great strides are being made in these areas and we can be optimistic. The opening of the Western fields has raised many issues for which we do not fully understand or have solutions for.

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THE IMPACT OF LIGNITE MINING ON SURFACE WATER AND MEANS OF ITS CONTROL

by

Henryk Janiak [x/]

INTRODUCTION

The surface mining of lignite affects environment in many ways. It can be seen in the change of micro-climate, in the change of the ground water and surface water regimes and in the change in the regional water balance.

Drawdown of the water table during exploitation affects simultaneously the drawdown of the ground water in the adjoining large areas of land. It causes disappearance or lowering of the water table in surface reservoirs, change of the flow character in the area of depression cone, reduction in the superficial run-off rate, and change in the air and soil humidity parameters.

Mine drainage changes water quality in surface flows and in reservoirs, (which serve as receivers of these waters). The magnitude of these changes is dependent on the rate and type of discharged pollutant load. Urbanization of the region due to the development of mining causes increase of the pure water consumption and increases also amount of sewage, which is important for water management in the region.

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x/ Henryk Janiak, M.Sc. POLTEGOR, Rosenbergów 25, Wrocław.

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The overburden storage which often occurrs on the elevated disposals, may induce local changes in direction and velocity of winds. This may also cause changes in the character and in the rate of surface run-off, in the distribution of atmospheric precipitation and changes in the phenological seasons of the year. There is also to remember, that lignite is usually being fired in locally sited power plants, the influence of which on surface waters is also very important, and it often combines with the influence of the mines.

From such a wide range of problems the paper presents only main problems referring to the influence of lignite surface mines on the water quality in surface receivers and to the means of protection within this range.

The aspects of quantitative effects are also briefly considered.

QUALITY OF WATERS DRAINED FROM LIGNITE SURFACE MINES AND THEIR INFLUENCE ON THE RECEIVERS

In the mine drainage one can distinguish two types of water i.e. "pure waters" and "dirty waters" (mine waste waters).

„Pure waters" are usually coming from the well system of deep drainage, and occassionally also from the underground galleries in the periods of time when in the galleries no mining operation takes place. This water is as a rule free of suspensions, colorless, with a chemical composition typical for the ground water in a given aquifer. It usually correspond to the first class purity of surface water and is discharged directly to the receivers without any treatment.

Polluted waters are coming from the active draining underground galleries and from surface drainage of an open pit.

Chemical composition of these waters during rainless periods is similar to the composition of the ground water, and differs from it during rainy periods.

Some parameters of the mine drainage are presented for particular mines in Table 1.

Table 1

Type of pollutants	Concentration unit	Turów I	Turów II		Open-pits of the Konin mine
B.O.D$_5$	mgO_2/l	0.8-4.2	1.2-20	1-4.0	3.0-6.0
Oxygen consumption	mgO_2/l	3-96 (30)	22-160(60)	6.4-39.0	8-52
Chlorides	mgCl/l	22-42	16-52	20-100	do 26
Sulphates	mgSO_4/l	270-480	204-350	50-150	0-40
D.S.	mg/l	650-1050	560-1000	do 400	270-600
Total suspended matter	mg/l	traces-1000	20-7200	60-2800	44-350
pH reaction	-	7.5-8.1	7.5-8.1	7.0-8.1	7.0-8.0
Total iron	mgFe/l	0.02-0.5	0.07-3.7	0.0-2.0	do 0.7
Color	mg/l Pt	10-30	30-90	15,20	3-50
Turbidity	mg/lSiO_2	10-1000	50-1000	10-1000	5-150

As it can be seen the main and often the only pollutant of the mine water exceeding the admissible levels are suspensions and attributable to it turbidity, and oxygen consumption.

The suspension consists of sand, dust, silts and coal grains of different shapes, dimensions and sedimentation characteristics.

The composition of suspensions greatly varies depending on the totality of mining, geological, drainage, and also of atmospheric parameters. The Table 1 indicates that concentrations of suspensions may vary from 20 to 8000 mg/l. The rise in suspension quantity is particularly evident after atmospheric precipitations and in times of snow melting, which is due to the increased intensity of a superficial run-off and to the erosion increase caused by the flowing water.

Taking into account given above concentrations annual quantities of suspensions (off-taken to the surface receivers from particular surface mines) have been listed in the Table 2

Table 2

Surface mine	Average quantities of drained dirty waters	Average suspension concentration in mine waters		Annual load of suspensions	
		Before treatment	After treatment	Without treatment	After treatment
	m^3/min.	g/m^3	g/m^3	tons/year	tons/year
Adamów	156	300	30	2400	240
Pątnów	70	180	30	6600	1100
Jóźwin	33	180	30	3100	520
Kazimierz	43	180	30	4100	680
Turów	31	1000	30	16300	490
Bełchatów (constr.)	120	200	30	12600	1900
Legnica (constr.)	35	200	30	3700	550

As it can be seen, the annual quantities of suspensions drained with the mine water are considerable. If not treated they could substantially affect purity of water in the receivers causing:

- decreasing of the flow cross-section and rising water of the table level by silting up and overgrowing of flows and reservoirs,
- increasing of the turbidity in receivers which inhibits the processes of photosynthesis and selfpurification,
- hindering of water purification processes in the case of its commercial or municipal utilization.

Increase of flows' pollution may in result change the utility value of flows and decrease disposable water reserves in the region. Therefore it is necessary to purify water so that not to exceed the admissible suspension level in the water receivers, which in majority of flows in the mine regions is 30 ppm as per the third class of water purity standard. Other types of pollutants usually do not exceed values admissible for the II class of water purity and bring no difficulties in mine waste water handling.

METHODS OF MINE WATERS PURIFICATION

Till now purification of mine waters is limited practically to the removal of suspensions in natural sedimentation processes in large field sedimentation basins. Initial removal of coarse fractions is taking place already in the basins adjoining the draining pumping stations.

The constructed basins for particulates sedimentation, have considerable capacities approaching 300.000 m^3 and surfaces of 22 ha. Their average depth varies from 1.8 to 3,0 m, and in the sedimentation part from 0.6 to 1.0 m.

The retention time according to the year of the basin construction varies from 1.4 full days to 7 days.

These retention times were used in the sedimentation basins constructed before the 1970. Present day basins have retention times within the active capacity zone of about 1 full day.

The effect of purification depends on the type of water and suspensions and varies from 20 to 60 ppm, which makes 65-95 percent of the total reduction. It can be reffered to the water from Konin and Adamów and mine region, where average level of suspensions do not exceed 300 ppm. More difficult to purify is water from the Turów mine, containing usually 500 - 1000 ppm of suspensions, and periodically even above the 7000 ppm. A design of the treatment plant basing on coagulation with lime is being prepared for these waters purification and the expected purification affect is to be 30 ppm.

STUDIED TECHNOLOGIES OF WATER PURIFICATION

Initiated in 1971 investigations on purification of mine waters had in view mainly improvement of the efficiency of sedimentation basins work. These investigations were performed on full scale and their subjects were mainly the hydraulics of water flow in large field sedimentation basins and the determination of interrelations between the retention time and reduction of the suspensions. As a result of these studies time of water retention in sedimentation basins with changed construction was cut down to 16-20 hrs, decreasing thereby its volume, while the results of purification remained the some.

On the basis of these investigations new recomendations for designing of field sedimentation basins have been prepared. The basic requirements regarding the dimensions of sedimentation basin elements necessary to optimum results in the suspension reduction, have been given.

According to these recommendations a new sedimentation basin has been constructed in the Konin Lignite Surface Mine. The effects of its work are very good. Also sedimentation basins for the Władysławów and Bogdałów open-pits were designed according to these guidelines. Realization of these basins is expected in 1978/79. These investigations showed that in properly constructed sedimentation basins mine waters polluted to an average or small level can be purified down to the value of about 30 ppm.

In the case of water with high level of difficult to sediment suspensions, e.g. Turow mine waters, this technology may appear to be insufficient.

Studies of other more effective purification methods, based on application of:

- gamma radiation
- flocculation
- filtration through sandbeds
- coagulation
- filtration through a so called "grass filter" were started as a part of work initiated in 1975.

The tests of the first three processes usefulness have been realized in cooperation with the US Environmental Protection Agency. They had shown a desirable radiation effect on the acceleration of suspensions sedimentation which is usually proportional to the absorbed dose rate of radiation. A practically good effect is observed at the dose rate 500 kRad and more. The greatest changes in the speed of purification under the influence of radiation shows water with high natural oxygen consumption and high turbidity. This was particularly apparent with waters from the Turow mine.

This technology was tested on a laboratory scale. Its practical utilization must follow multidirectional investigations on a full scale carried out in a pilot research station. The scope of the research work, apart from the observations of purification effects should include long term observations and investigations of the purified water influence on plants and animals. Therefore one does not expect practical introduction of this method in the Polish lignite mines.

The second investigated technology involved use of synthetic flocculants in purification of mine waters. These investigations were performed on a laboratory and on a full scale in a special experimental sedimentation basin built in the Adamów mine. Eighteen types of flocculants (of Polish and American production) have been used for the tests.

Laboratory and field tests have proved high usefulness of kationic polymers in water purification from suspensions. Most effective were kationic polymers of the Calgon firm, particularly the Calgon M-502 and Calgon M-502. The best of the Polish polymers was Rokrysol -

WF-5. Required doses of these flocculants were from 0.1 to 5 ppm, and were dependent on the origin and quality of the treated water, and also on the method of flocculation process.

Good for purifying with flocculants was water from the Adamów and Konin mines. Results of these tests represent curves of the dependence between the retention time, the flocculant dose and the percent of turbidity reduction, shown on Fig. 1.

The Turów mine water frequently required doses exceeding 5 ppm and the their purification results were not always sufficient. An essential factor in the process of water purification with use of flocculants was application of their right dosing and the method and time of rapid mixing.

With the use of Calgon M-502 optimum concentration of the solution was from 0.1 to 0.5 percent, while the optimum time of rapid mixing, independently of the dose amount, was from 8 to 10 mns (when mechanical or air and mechanical mixing was applied).

Detailed results of the above studies can be found in special report published by EPA.

NEW IDEAS IN THE STUDIES ON WATER PURIFICATION

The investigated techniques of water purification, based on dosing chemicals, which accelerate sedimentation of suspensions, are rather burdensome, costly and labour consuming in exploitation. Hence the reluctance to use them in practice. This dictated the necessity to analyse such methods which together with natural sedimentation would allow to increase the effects of water purification and to make them independent of the atmospheric conditions.

A two stage technology of water purification has been suggested. At the first stage water would be purified in a sedimentation basin with retention time of 10-16 hours where sedimentation of coarse fractions, partial reduction of turbidity, heating of water, and levelling of runoffs would take place. At the second stage initially purified water would flow through the area planted with selected species and water or of plants, called a grass filter.

Preliminary observations of the periodical flow of mine water through lands covered with bog and peat vegetation had shown a very high (almost total) removal of the suspensions. Literature data from Polish, American and German publications indicate that almost all marsh plants show the ability to purify water. Such plants as the common reed (Phragmites communis), yellow flag (Iris pseudocorus L.), sweet flag (Acorus calamus) common rush (Juncus effesus), sedge (Corex rostrata), and many others were found to have such properties.

These plants can also neutralize toxic substances such as cyanides, rhodanates, phenols in water. They show also disinfecting properties killing the pathogenetic germs not only in summer, but also in winter, though to a smaller extent. They have also the ability to accumulate solts in their tissues and thereby contribute to de-eutrophization of water.

Finally one may state, that marsh vegetation complexes are functioning in nature as an immense grass filter and at the same time as a powerful sorbet disinfecting water media from toxic organic and inorganic substances and from pathogenic bacteria.

These properties induced many countries to establish artificial plantations of these plants to purify all sorts of sewage.

Such plantations purify domestic, sewages in West Germany, sewage from camping sites for 5000 people in Holland, sewage from a slaughterhouse in U.S.A., from a sugar factory in East Germany, from a steel works in Romania.

These are vegetation biocenoses rather than single species.

The above data induced to analyse the usefulness of march plants for purification of mine water.

These waters are characterized by a relatively even temperature, high turbidity, and often high oxygen consumption and high content of biogenic substances. These factors have an essential influence on growth and development of marshy vegetation.

These problems are a subject of research initiated in 1977 in co-operation with Academy of Agriculture in Wrocław.

Financing of this research from the Polish-American M. Curie - Skłodowska fund is expected since 1979.

These investigations have mainly in view:

- determination of a specie or of a complex of species of marsh plants which well tolerate conditions of the mine water medium,
- determination of a selected species' usefulness for purifying water from suspensions, and defininf of the expected effects,
- providing of basic technical parameters for the design of a grass filter.

These investigations are carried out in the Adamów lignite mine, In future observations are planned to be carried in the sedimentation basin for water purification of the Bełchatów Lignite Mine, constructed in 1978/79.

In this mine drainage water will be purified with use of this technique in quantity of about 160 m^3/min.

This sedimentation basin will consist of 5 main chambers. In every main chamber the inlet part is the normal sedimentation bay and the outlet part the grass filter bay. The basic plants intended to introduce are:

- marsh sedge (Corex acutiformis)
- common reed (Phragmites communis)
- ribbon grass (Phalaris arundinacea)
- reed sweet grass (Glyceria aquatica).

The expected effect of water purification in the designed sedimentation basin in the Bełchatów Lignite Mine is under 30 ppm, at the reduction value of about 85 percent. This sedimentation basin is at the same time used as pilot basin for the observations on full scale of this technique usefulness, which are carried out as a part of investigations on grass filter application in mine waters purification.

Positive results of these tests will enable to prepare an effective and cheap technique of water purification and thereby will, contribute to the decrease of undiserable effects of lignite surface mining on environment.

QUANTITATIVE IMPACT OF SURFACE MINING ON SURFACE WATER

Problems related to the quantitative impact of lignite surface mining on surface water have not been so far a subject of specialistic, complex studies. Fragmentary investigations, comprising often short observation periods, resulted from the need of planning of a hydrographic network regulation in the mine region, draining an excavation or disposal ground, and are not sufficient to provide detailed characteristics of all aspects of this impact. Nevertheless they served together with observations carried out on lands of the depression cone reach - in the Konin and Bełchatów region of - to find basic directions of this influence. It has been found surface mining causes:

1. Disappearance or drawdown of the water table in water reservoirs, dewatering of the marshland or peat lands, liquidation of fish ponds etc.
2. Decrease, and even disappearance of average and low flows in the water-courses which are not receivers of drainage water, and their increase and levelling in flows being a part of the mine water offtake from the system.
3. Lowering of water filling and increasing of water flow velocity in flow beds effected by their canalization.
4. Serious changes in movements of rubble in water courses.
5. Changes of the elements of the region's water balance, mainly due to the decrease of surface water drifts, to evaporation, to the increased infiltration of rain water, and to underground flows.
6. Changes of soil and air humidity.

Extent of particular elements' influence depends on such factors as:

- type and permeability of soil
- degree of self-sealing of water race beds and reservoirs bottoms
- distribution density of hydrographic network
- morphology of land
- land utilization etc.

Problems of the mine impact are additionally complicated by the influence of power plants. Therefore while studying these problems one should distinguish two periods.

The first period includes the construction of mine until the power plant is put into exploitation, and the second period which comprises exploitation of the mine and the power plant.

Occurring in the first period surplusses of water in low and average flows are used in the second period by the power plant, affecting negatively water balance in the region. Then can occur a necessity supply water from other, frequently very remote, watersheds. This can be very expensive.

The attempt to forecast changes of basic elements of water balance was for the first time undertaken in the region of the newly constructed Bełchatów mine.

It has been indicated, that as a result of draining the surface run-off in the mine region will diminish by 30 percent, evaporation from the terrain surface by about 16 percent, and evaporation of the ground water by 70 percent. However the underground run-off to the draining system will increase by 107 percent, and the rain water infiltration rate by about 70 percent.

These parameters are essential for general determination of mine impact on environment. They are assumed to be introduced on the basis of field experiments. It requires however long term and complex regional investigations carried out on a large area and long before the mine construction.

RELATIONSHIP BETWEEN THE DOSE OF CALGON M - 502, THE TIME OF RETENTION IN SEDIMENTATION CHAMBER, AND THE TURBIDITY REDUCTION

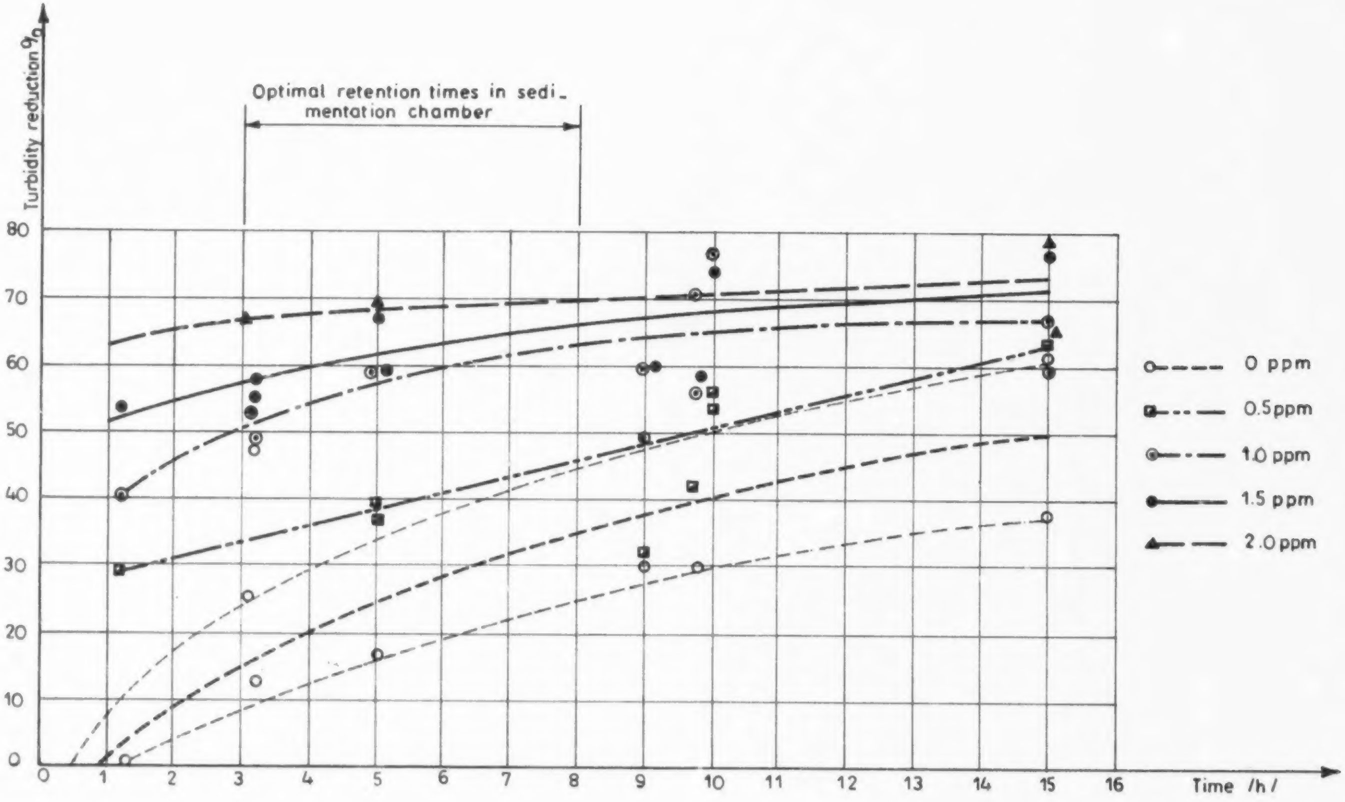

FIG.No 1

COAL REFUSE DISPOSAL PRACTICES AND CHALLENGES IN THE UNITED STATES

John F. Martin[x/]

INTRODUCTION

On August 3, 1977, the Surface Mining Control and Reclamation Act of 1977 was signed into law. The Surface Mining Reclamation and Enforcement Provisions supporting the law define coal waste as "earth materials, which are combustible, physically unstable, or acid-forming or toxic-forming, wasted or otherwise separated from product coal and are slurried or otherwise transported from coal processing facilities or preparation plants after physical or chemical processing, cleaning, or concentrating of coal. (1). The regulations also state that "toxic-forming materials means earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are detrimental to biota or uses of water". The handling of waste, refuse, slurry, and gob is a practical problem for the coal industry and one set apart for special consideration by law. Proper disposal of these by-products or utilization of them for construction or production of other products remains as a challenge to the United States and to all coal producing countries.

Statistics for the coal industry in the United States show that 1975 production for bituminous coal and lignite was 588 million metric tons (2).

[x/] John F. Martin, Extraction Technology Branch, Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

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This figure can be further divided into underground production of 266 million metric tons and surface production of 323 million metric tons. In 1971 approximately 50 % of the domestic lignite and bituminous coal produced was the result of underground mining methods. The production emphasis has since moved to surface mining. Of the coal produced in 1975, 41.2 % was mechanically cleaned yielding 97 million metric tons of waste material.

The mechanical coal cleaning plants in the United States are clustered in the eastern and interior coal provinces east of the Mississippi River. The 1975 statistics show that the largest number of cleaning plants are in West Virginia, and the eastern states as a whole account for more than 360 of the total 388 plants recorded. Wet jigging and dense medium processing continue to be the most popular mechanical coal cleaning techniques.

A summary of production trends indicates that the waste handling problem is increasing. Bituminous and lignite coal cleaning wastes rose from 81 million metric tons in 1971 (3) to 97 million metric tons in 1975. As a result of increased production of low sulfur coal and more careful and selective mining procedures, the percentage of coal that was cleaned in 1975 (41.2 %) was less than that in 1971 (49.1 %). Selective mining or washing of all coals, however, is becoming more important as environmental concern increases (4).

ENVIRONMENTAL CONCERNS

The coal waste disposal problem bears equally on air pollution, water pollution and land use. In addition, the disposal site is often considered to be aesthetically offensive.

A loosely packed refuse pile that contains a large amount of combustible material is a prime candidate for spontaneous ignition and a refuse pile fire is extremely difficult and dangerous to quench. The resulting fumes have a high sulfur oxide content and present a serious health hazard to the nearby population. Of 135 active refuse piles recently visited in Pennsylvania, 19 had signs of fire. In addition to fumes from refuse fires, fine refuse particles carried by the wind are a source of considerable dust.

A source assessment performed by Monsanto Research (5) attempted to summarize the severity of the air pollution problem resulting from burning coal refuse piles. Estimates of the yearly national mass emissions from burning coal refuse were: particulates - 190 metric tons; sulfur oxides - 39,000 metric tons; nitrogen oxides - 34,000 metric tons; total hydrocarbons 34,000 metric tons; carbon monoxide - 4,500,000 metric tons. Other atmospheric pollutants detected from burning waste areas included polycyclic organic materials, hydrogen sulfide, ammonia, and mercury.

Water is polluted by coal waste in basically two forms: acid drainage and siltation. The acid drainage formed by mine waste varies according to location, seams, compaction, cover material, etc. Although coal seams vary locally and by region, there appears to be less of an acid drainage problem in southern West Virginia, eastern Kentucky, and the western coal provinces of the United States than in other coal producing areas.

Siltation is directly influenced by the steepness, compaction, drainage control structures, and cover material of a waste or refuse pile, Work at the Truax Traer refuse pile (EPA Grant 14010 DDH) in Illinois has shown that even the moderately sloping sides of a pile are susceptible to severe erosion (6). A stable grass cover, often difficult to establish on refuse, is essential if erosion is to be controlled.

Water moving through coal waste picks up the sulfuric acid that has been generated by oxidation of pyritic materials. The acid, in turn, enables the water to dissolve extremely large quantities of iron, aluminum, and other heavy metals. Previous studies have indicated that effluents from coal waste areas contain significant quantities of zinc, copper, nickel, iron, lead, boron, magnesium, and manganese. An Environmental Protection Agency (EPA) survey (7) found that the effluent from an Indiana waste site had a pH of 2.4, acidity of 6500 mg/l, and iron concentration of 2600 mg/l. In addition, the zinc and manganese concentrations were 7.2 mg/l and 120 mg/l respectively. The suspended solids loads may range into the thousands of milligrams per liter, depending on the amount of flow, stream gradients, and characteristics of the waste pile.

Studies at the University of South Carolina (8,9) have shown that only the framboidal form of pyrite (smaller than 0.5 micron) in coal and coal wastes produces abundant acidity. In disposal or reclamation efforts it would be of benefit to be able to predict the acid potential of the waste material, so research was undertaken to present a point counting technique for quantitatively estimating acidity production.

Very few studies have been carried out in the United States to document groundwater pollution problems associated with mining, especially regarding the effects of coal waste disposal.

One short-term monitoring effort of an abandoned coal waste pile was undertaken by Argonne National Laboratory at Consolidated Mine No. 14 in Illinois (10). The mine waste was highly eroded and generated an acidic surface discharge. Twenty-seven wells were placed in and around the disposal site in order to monitor the shallow groundwater system. Thirteen residential wells in the area were also sampled. The water table was about 3 m below the ground surface near the waste pile and sloped away from the pile in all directions. At wells within 130 m of the waste pile the pH values were low, while acidity, sulfates, and several metal ions were extremely high. At one particular well near the waste pile, the pH was 2.4 and acidity, sulfate, and aluminum concentrations were 8370 mg/l, 2722 mg/l, and 980 mg/l, respectively. Values of iron, manganese, and zinc were recorded at 394 mg/l, 7.0 mg/l and 123 mg/l, respectively. Water quality greatly improved at distances greater than 130 m from the pile. Combinations of dispersion, adsorption, cation exchange, and precipitation were cited as possible processes involved in improving the water quality.

A joint study by Poland's Central Research and Design Institute for Opencast Mining Poltegor and the United States Environmental

Protection Agency, carried out in Poland, showed that coal waste disposal piles had a negative effect on groundwater quality (11). The study, involving disposal of coal waste and fly ash, snowed there was significant contribution of sulfates, chlorides, sodium, potassium, boron and other ions from the waste material to the groundwater.

Streams affected by drainage from poorly constructed coal waste disposal sites are rendered useless for many miles. The most abvious effect of such pollution is the destruction of aquatic life. Even after a waste pile is reclaimed, the effects of silt accumulation on the bottom impact the spawning areas of fish populations for many years. Such streams, polluted by acid drainage and suspended materials, afford no recreational use. They are basically unfit for cooling water, of no good for irrigation, and require extensive treatment before they can serve as a domestic or industrial water supply.

The impact of coal waste disposal on land use is basically one of reducing future alternatives for development. In some cases reclamation efforts have turned waste piles and slurry ponds into pasture land, building sites, and recreational areas, but these examples are in the minority. It is expensive to correct a problem area after the damage has been done. Proper planning and construction, aimed toward pollution control and post-reclamation land use, is a proven, effective tool for solving the land area problems associated with disposal of waste or toxic-forming materials. Often the flat surface of a coal waste disposal area can serve as an economic asset in mountainous or steeply sloping terrain where flat building sites are scarce.

CURRENT PRACTICE

The culm bank, refuse pile, or coal waste heap was, in the early coal mining days, the easiest spot for random dumping. It may have been adjacent to the preparation plant, over the nearest hillside, or in a stream bed. Our failure to properly plan and engineer these waste sites has caused many of them to be environmental hazards. Today, the careful construction of refuse piles is essential.

Various methods have been employed to transport material to the waste dump (12,13). Each system was developed to take advantage of the terrain and to apply to the type and quantity of waste material produced. Small size wastes in slurry form are readily pumped to the disposal site, while coarser fractions must be transported in some other manner. The most popular haulage technique today for coarse wastes is by truck. It is essential that the disposal site be well shaped and compacted. Ground machinery should be used in conjuction with trucks to spread and compact material. A sheep's-foot roller greatly increases the effectiveness of the dozer in compacting thin layers. On many active disposal sites the truck drivers are being encouraged to drive to the dumping location on a slightly different course each trip to aid in compaction. Pans or scrapers also can be used effectively to spread the material in thin layers, to form the waste pile, and to compact it.

The aerial tram is a popular haulage tool for solid wastes in mountainous regions, but it does a rather poor job of forming a stable pile. As the material drops, it tends to segregate into coarse and fine fractions. The side slopes rest at a steep natural angle of repose, and there is relatively no compaction. A dozer, when used in conjunction with a tram is helpful in building the pile, but can accomplish less compaction than when trucks are used for haulage. Belt haulage of waste also requires some type of ground machinery to spread and compact material at the site.

Many of the huge anthracite culm banks in Pennsylvania were formed by dumping material over the end of the pile, and raising the road or mine car tracks as the pile grew. Often these piles burned because of their porous structure and low density they were riddled by erosion and polluted the surface drainage with silt. Excessive surface acidity or heat from the sun kept most of them devoid of vegetation (14).

The angular character of coal waste particles or refuse often allows it to rest at a steep slope. One anthracite refuse pile in Eastern Pennsylvania held 35 degree side slopes; bituminous coal refuse on a hillside dump in Eastern Kentucky held 30 degree side slopes. These slopes are often subjected to high pressure from winds, and allow air to be forced through the pile contributing to pyrite oxidation and spontaneous combustion.

Since combustion and acid mine drainage require oxygen in their processes, oxygen most logically is the factor to control at the waste disposal site. With regard to runoff and leachate, oxygen is necessary to convert pyritic material into ferrous iron and sulfuric acid. The acid in turn increases the ability of the water to dissolve heavy metals and to carry them to the receiving stream. The density of the pile, size of material, water content, and side slopes contribute to the rate of oxygen entry.

For stabilization and control of the refuse pile, it is necessary to compact the material as it is placed. This reduces the air voids, increases the bearing capacity, and reduces the possibility of slides and slope failures due to excessive water content. To aid in halting the movement of oxygen, a sealant (such as plastic, cementing agents, clay) can be placed over the pile (15). Vegetation on a refuse bank further aids in trapping oxygen, because the humus that develops forms a moisture barrier and demands oxygen itself. In certain instances it may prove feasible to seal only the sides of a compacted pile, thereby cutting off most of its oxygen supply. Various research projects are currently investigating a host of surface sealants, including gypsum, wood chips, fly ash, waste cement, and various types of vegetation and earth materials (16,17,6).

In response to the Buffalo Creek Disaster of 1972, the Mining Enforcement and Safety Administration published design and inspection manuals (18,19) to establish uniform construction and regulatory procedures for coal refuse disposal facilities. The design manual covers such topics as the origin of coal refuse and waste, classification of disposal techniques, general planning and design techniques, geotechnical investigations, hydrologic considerations, environmental factors, construction procedures, and monitoring systems. The Administration classifies disposal facilities as impounding (cross-valley, side-hill, diked pond, incised pond, other) or non-impounding (valley-fill, cross-valley, side-hill, ridge, heaped, other) structures to facilitate monitoring and inspection. The current regulations of the Surface Mining Control and Reclamation Act of 1977 do not cover disposal of coal refuse except in surface mine pits or other backfilled and regraded areas. The final regulations are expected to cover environmental and safety considerations in off-site disposal of waste in ponds, piles, or various types of valley-fills.

Recently, many mining companies have begun to return waste materials, refuse, and toxic-forming materials to the surface mine pit for disposal when feasible. They have made efforts to integrate disposal and reclamation plans to safely and effectively solve their coal waste problem. A pronounced advantage of returning waste to the surface pit is the fact that no pile or fill is constructed and no other land disturbance is required beyong the actual mine pit. Operations of this type are extremely well suited to area mining operations with onsite coal preparation or washing facilities.

Returning coal wastes to the worked-out voids in underground mines is much less common. Backfilling has long been common practice in metal mines, but it is rare for coal mines (20). Some hydraulic backfilling is accomplished, however, in abandoned mines for subsidence control. In this case, utilization and disposal of coal waste materials is combined into one operation.

The initial regulations (21) published by the Department of the Interior in support of the Surface Mining Control and Reclamation Act of 1977 set forth partial guidance for future waste disposal operations. The regulations basically provide for covering all toxic-forming, acid-forming, combustible, and waste materials with a minimum of 1.2 m of nontoxic material as a part of the backfilling and grading operation of a mine site. In addition, it must be demonstrated to the regulatory authority that the use of waste materials will not adversely affect water quality, flow, vegetation, or stability in the backfilled area, and that the use of waste will not present a public health hazard. All activities associated with the mining operation are to be conducted in such a manner as to minimize impacts to the prevailing hydrologic balance. The section of the regulations dealing with disposal of spoil and waste materials in areas other than the mine workings or excavations does not currently deal with waste or toxic forming materials except to specifically prohibit disposal of combined spoil and waste in valley or head-of-hollow fills.

Water quality standards set forth in the regulations apply to all surface drainage from the disturbed area. This provision would necessarily include waste materials being returned to the mine pit for backfilling and disposal. After being routed through a sedimentation pond or series of pond, the surface drainage must meet effluent limitations as indicated in Table 1.

Table 1. Point source coal mine effluent limitations

Effluent Characteristics	Maximum Allowable	Average of Daily Values for 30 Consecutive Discharge Days
Iron, Total	7.0 mg/l	3.5 mg/l
Manganese, Total	4.0 mg/l	2.0 mg/l
Total Suspended Solids	70.0 mg/l	35.0 mg/l
pH	Range 6-9	

There are exceptions to the limitations on a case-by-case basis for some western states and in cases where high manganese levels are encountered. In addition, discharges from the disturbed area within the permit area resulting from precipitation in excess of the 10-year, 24-hour event will not be subject to the above effluent limitations.

The use of coal waste material in dam construction, and any dam to impound waste materials must be directly approved and supervised by the regulatory authority to ensure stability, safety, and operating characteristics.

DISPOSAL RESEARCH

In order to develop more advanced and economical methods of coal refuse disposal and abandonment of disposal areas, various research and demonstration projects have been undertaken by state and federal agencies and private industry. One such project was accomplished as a joint venture between EPA and the Consolidation Coal Company at the New Kathleen Mine in Illinois (23). An abandoned refuse pile was regraded and covered with soil material to determine the effectiveness of different thicknesses of earth cover in reducing acid runoff from the refuse. In general, it was found that acid production was controlled by covering and revegetating the pile and that no significant difference was observed among 0.3, 0.6, or 0.9 m soil covers. Before reclamation, runoff from the pile had a high iron content with a pH value of 2.0. After completion of the project, the effluent from the pile was of good quality with but a few tiny acidic seeps along the toe.

Two problems related to the surface soil covering were encountered in the reclamation of the pile. First, although no significant water quality or vegetation difference was detected among the various soil cover thicknesses there was a problem in controlling the 0.3 m soil application. With such a thin soil blanket, the construction equipment gouged some spots of the pile and overcovered others. Secondly, several of the side slopes on the pile were so steep that gullies eroded into the waste material. Later, remedial action was necessary to repair the damage.

From a feasibility study conducted by EPA and the State of Indiana at the Greene-Sullivan State forest, it was pointed out that leveling and covering large refuse areas is extremely expensive (23). The project area consisted of a large refuse pile and adjacent acid lake. The restoration program was to include grading, covering, revegetating and permanently inundating portions of the refuse. These procedures were designed to break the cycle of erosion, exposure of pyritic material, oxidation, acid formation, and erosion. The lake had a pH value of 2.8, with sulfate, iron, and magnesium concentrations of 1,700 mg/l, 100 mg/l, and 100 mg/l respectively. The demonstration phase of the project was not accomplished because of the prohibitive cost.

In 1971 the Peabody Coal Company and Illinois Department of Mines and Minerals began a cooperative study for direct seeding of coal refuse after lime was added to soil (24). Seed and fertilizer were added at two study areas but growth at the end of the first growing season was almost neglible. Additional plots were vegetated with increased lime application rates and these showed more favorable results. One area also received a 15-cm soil layer in addition to a lime treatment of 48 tonne/ha. This area showed what seemed to be superior vegetation compared to the others that received lime only. The study showed that vegetation could survive on refuse material with proper lime neutralization. Initial results showed that about 11 tonne/ha of lime, incorporated to a 15-cm depth, was necessary for each one percent of sulfur in the refuse material.

Disposal of fine coal refuse is also receiving some research and demonstration efforts. Fine refuse in slurry form may be dewatered mechanically and placed in a waste landfill, dewatered in a holding pond for future landfill disposal, or permanently impounded in slurry form. With many preparation plants now recycling the slurry water, excavation of settling or storage ponds is becoming more common. The fine coal refuse is, however, difficult to excavate, difficult to haul by truck, and nearly impossible to compact in a fill.

An approach to the problem, which seems to be gaining popularity, is to add a stabilizing agent to the slurry material in order to help it again shear strength and reduce its permeability. The Island Creek Coal Company and Dravo Lime Company have demonstrated that treated refuse can be excavated and used in a landfill (25). The slurry material, treated with Calcilox, was handled, spread and compacted with conventional equipment immediately after being excavated from the holding lagoon.

COAL WASTE UTILIZATION

Utilization of coal refuse and waste materials offers several advantages over mare disposal. As a by-product material, coal waste can be used as a fill or construction material, processed for use as an aggregate material, or supplied as a raw feed for extraction of coal and other elements carried in it.

Use of coal mine waste material for backfilling of mine workings in the United States dates back to at least 1864 when a church in Pennsylvania was saved from coal mine subsidence by stowing preparation waste in the void beneath the building. The practices of controlled placement and blind flushing of refuse into abandoned mines has continued to be a control technique for subsidence. Because of the porous and compressible nature of the backfilled material, the use of a binding agent such as portland cement, would be necessary to consider a coal waste backfill as a total subsidence prevention technique.

In 1972 and 1973, the Bureau of Mines, U.S. Department of the Interior, undertook a full-scale demonstration of coal waste backfilling (26). Nearly 344,900 cubic meters of refuse were pumped in water-slurry form into mine voids below Scranton, Pennsylvania. Five injection boreholes were used with a network of observation holes to minitor progress of the operation. Pressure at the slurry pump delivering material to the holes was maintained at a gauge reading of 4.2 to 6.7 g/sq cm. The waste material ranged in size up to 12.7 mm.

The work demonstrated that coal mine waste could not only provide some measure of protection against subsidence, but that utilization of waste material eliminates the need for surface disposal. This secondary environmental benefit also extends to a reduction in air pollution from burning of abandoned waste piles and reduction of surface water pollution emanating from acid drainage. Hopefully, the backfilling process will effectively seal any acid generating materials from oxygen contact and thereby eliminate any future water leachate problems.

At the Orient No. 4 mine in Illinois, the Freeman United Coal Mining Company conducted a similar demonstration of stowing mine waste underground (20). Their work differed from that previously cited in that the mine was active and not abandoned. Since 80 % of the refuse material at Orient No. 4 was less than 1mm in size, it was pumped directly from a preparation plant to a worked out section of the mine. The refuse slurry was fed to the underground void by gravity at 5.3 % solids. It appears that the total extra cost of injecting the slurry underground as opposed to ponding it on the surface was about $0.60 per metric ton. Even with the extra crushing required, the costs of returning both coarse and fine refuse to the mine void may be economically feasible where surface disposal systems are either impractical or expensive.

Various other coal refuse utilization projects have been undertaken in the United States. In Pennsylvania, refuse has been used for highway fills and shoulders, and has been reprocessed and leveled for equipment parks and industrial building sites. A major concern about the use of coal waste is its potential for water pollution. Any utilization project must consider the composition of the refuse material, its size, and strength.

The Extraction Technology Branch of EPA performed an in-house study of coal waste material used as a base course for construction of a parking apron. Three test sections were installed to investigate the water quality of leachate from an all-refuse base, a refuse - fly ash base, and a refuse - fly ash - lime base. After five years the latter two areas exhibited a yearly average leachate pH value greater than 6.0, and iron and aluminium contents were less than 1 mg/l and 15 mg/l, respectively. The test section using an all-refuse base continues to leach acid water with high metals content. These preliminary results indicate that the refuse needs to be blended with an alkaline material before use. Though the water quality of leachate from the all-refuse area is relatively poor, only a very small quantity collected; thus drainage protection, encapsulation or surface sealing might serve to protect the environment from adverse impacts.

Considerable research and development efforts have gone into the utilization of coal mine waste and refuse in a slightly altered form. Through sintering or roasting processes, coal refuse can be converted to a fairly inert, durable, lightweight aggregate for use as a medium for vegetation or construction material. When coal waste is subjected to high temperatures, on the order of 1300°C, sulfur tends to gasify, volatile materials are driven off, and carbonates and organics are decomposed. Other constituents are either reduced or oxidized leaving a stable product which is sterile, chemically inert, and full of fine holes. Studies at the University of Kentucky (27) have demonstrated that this type of product from coal refuse serves well as a growing media for containerized plants and does not release chemicals which are toxic to the plants.

The material described above is similar to the incinerated refuse produced at burning refuse and gob piles. For years, incinerated refuse or "Red Dog" has been excavated for use as a highway fill material and skid preventive road coating. This naturally occurring material may vary considerably in physical and chemical composition, however, from one refuse dump to another.

Other studies at the University of Kentucky were undertaken to investigate the use of sintered coal refuse in portland cement concrete, bituminous concrete, and concrete blocks (28). This lightweight aggregate performed well in all three applications. Its strength was slightly lower than that of control specimens constructed with limestone aggregate, but this is more than offset by the benefits of the lower unit weight of the sintered coal refuse mixtures. One benefit noted in the use of coal refuse for sintered aggregate production was the extra heating value from coal left in the refuse by the cleaning process.

Coal refuse material is also being used in the United States as a resource for additional yields of coal and for a source of other raw materials. Advanced processing methods and equipment have made possible the reclamation of thousands of tons of coal from old waste piles and slurry ponds. In the area of fine coal recovery, tremendous resources are available from disposal sites where fine coal was placed as an unuseable waste. Anthracite coal waste banks are especially suited for reprocessing because of the relative cleanliness of the fuel from an environmental standpoint and the economic value of the product. Immediately proceeding the mine backfilling work at Scranton, Pennsylvania, the refuse piles were reprocessed for a second yield of steam coal.

Aside from coal itself, aluminium seems to be the next most economically recoverable component of coal waste. The U.S. Bureau of Mines has found that ash from most any type of coal refuse contains about 24 % Al_2O_3 (29). Recovery of this aluminium, and some additional heat value, may help to offset the ash handling and air pollution problems associated with burning coal refuse. Other elements, such as iron, calcium, magnesium, manganese, titanium, etc., are also found in coal waste. These too, to varying degrees, may be recoverable, based on future supply and demand and on advanced recovery processes.

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RECLAMATION PRACTICES FOR COAL REFUSE AND FLY ASH DISPOSAL

by

Władysław Wysocki[x/]

INTRODUCTION

Coal mining industry and power industry using coal produce considerable quantities of wastes.

In 1977, the total quantity of coal refuse in Poland reached 46 million m^3 (4). Every ton of coal is excavated with 0.41 ton of waste, and in some mines this index increases up to 1.40 t. It is predicted that the production of coal refuse will continue to increase, and by 1990 the production of wastes will rise to about 56 million m^3 yearly. Today, deep mines make up some 37.6 % of the total coal refuse. The contribution of coal processing plants equals 60.2 %, and that of the mine boiler houses (fly ash and bottom ash) is 2.2 %. Hydraulic stowing has a considerable part in a reasonable utilization of coal wastes (17 mil.m^3). About 26 mil. m^3 of wastes are yearly stored on disposals. The average height of the piles is 10 m, which increases the area of storage by more than 260 ha yearly (incidental terrains not included).

The areas of disposal for coal refuse generated by the coal industry can be-classified into 2 groups (9):

A - tailing ponds are used for the storage of hydraulically offtaken waste sludge generated during coal dressing (floatation or washery) in treatment plants; the deposited sludge is compacted with time

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[x/] Dr. Władysław Wysocki - Principal Investigator, POLTEGOR Rosenbergów 25, Wrocław due to the loading exerted by the superimposed layers; related to the ground level, these disposals are either above-level disposals (staging) or sublevel disposals.

B - disposals contain solid wastes generated in deep mining and mechanical treatment plants.

The classification of disposals is as follows and depends on (9):

a) the location (in relation to the place of waste production):
  - disposals on plant sites (mines) belong to a particular mine, usually cover a small surface area and are situated in urbanized terrains,
  - central disposals are located outside the urbanized area; they are utilized by a number of mining companies, and serviced by a special company;

b) their shape:
  - the sublevel disposals, whose crown tops flush with the ground level or are below the ground level (depressions in the land as caused by subsidence in effect of deep coal mining, or adopted roof fall operations),
  - the above-level disposals with crown tops above the level of the adjacent lands; included here are also cone-shaped disposals;

c) the type of the material stored:
  - deep mine sterile rocks accompanying coal (clay rocks, mudstones, sandstones, gritstones, limestones, tuffites)
  - sterile separated in dry processing plants
  - washery wastes
  - non-homogeneous combinations of the waste materials mentioned above;

d) thermal activity
  - the not overheated, thermally passive disposals, constructed of inflammable materials

- overheated disposals, in which the process of coal substance combustion was completed,
- thermally active disposals (burning, aflame) or containing large admixtures of coaly substance,
- thermally passive disposals, with fires put out, or cool;

e) the grain size of the materials stored and the degree of weathering, with emphasis on the soil content and susceptibility to weathering processes.

Fly ash and bottom ash produced by power plants, as well as heat and power generating plants fired with bituminous coal or lignite, form a special group of waste materials. The quantity of fly ash and bottom ash generated from bituminous coal approaches 17.5 million tons, and that generated from lignite equals about 12 million tons per year. Considering that the average height of the disposal is 10 m, it is evident that additional surface areas of at least 300 ha will be needed each year for the storage of these waste materials. The production of fly ash and bottom ash, however, will continue to increase, and in 1990 is predicted to exceed 30 million tons and 20 million tons for bituminous coal and lignite, respectively.

Wastes generated by the power industry are classified to two groups, depending on the coal burnt (9):

a) ashes produced from burning bituminous coal, and
b) ashes produced from burning lignite.

The waste materials referred to as (b) are characterized by various chemical composition and may therefore be divided into sulphatic-calciferous ashes (from the Miocene deposits in Central Poland), into aluminous silicates (from Miocene deposits in the region of Turoszów) and into calcium aluminous ones (from the Bełchatów Miocene deposits). Considering their pH' reaction, the wastes of interest are either alkaline (those from Central Poland and Bełchatów) or neutral (those from the Turoszów region).

There are two methods of storing and transportation of those wastes from the power plants;

a) wet storage with the use of hydraulic transportation - the disposals are characterized by flat, even surfaces, the escarpments are made of mineral soils (lower layers) and have a considerable grain distribution which is due to the sedimentation process of material in the water,

b) dry storage with the use of pneumatic transport or haulage - the surface of the disposals is fairly irregular, and the chemical composition and the grain size of the waste materials stored are nonhomogeneous.

With respect to location two types of ash disposals are distinguished:

- above-level disposals with escarpments made of soily material or of consolidated ash, and
- sublevel disposals located in land depressions.

CONSTRUCTION OF DISPOSALS AND THE RECLAMATION REQUIREMENTS

Considering the serious environmental hazard created by toxic - waste disposal on a site near the power plant (air pollution, contamination of ground - and surface waters, run-off etc.), a reasonable management of those waste materials requires that they be disposed off on large central sites. Abandoned old open pits and waste land, depressed and with no run-off, as well as arable and forest lands of a poor soil quality are especially fit for this purpose. Forbidden is disposals location on arable and forest lands of good quality. Forbidden also is planning of such disposals in protection zones of springs and water intakes and in flood areas of rivers.

The design of hazardous waste disposals should include an optimum utilization of transporting and stacking machines, to achieve the required geometrical shapes which will allow a later reclamation of the surface with minimum earth work, and grading. The storage of wastes is conducted in a manner affording an eventual future utilization of the materials stored as secondary raw materials.

Hence, it is required that the wastes be disposed of separately:

a) with the exception when a combination of different waste materials is indispensible for a reasonable disposal or management, and

b) the properties determining the future utilization of the wastes be preserved.

To prevent their vicinity the following safeguards are considered:

1) Run-off and seapage water can be discharged to the superficial water system, if either no toxic substances are present or appear in admissible concentrations; in any other case a pretreatment is needed, to prevent contamination.

2) In the adjacent land the ground water table should be maintained as required by agricultural or forest use of such terrains.

3) Aquifers should be protected against entering the seepage water especially when the disposal subsoil is permeable.

4) The site for hazardous waste disposal should be managed in such a manner that no emissions of particulates and gases to the air in excess concentrations take place; this can be achieved by consolidation of the surface and planting of protective woody species.

ASH RECLAMATION

Coal refuse produced by the coal industry can be classified from the petrographic point of view as (2):

a) carbonaceous rocks (containing 32-70 % of coal derived from carbonaceous vegetation), which constitute about 5 % of wastes and are characterized by the readiness to self-ignition;

b) argillaceous rocks (with predominant occurrence of clayey minerals such as kaolinite, montmorillonite, illite) of a low coal content;

c) sandy shales (with high quartz content), which occur in large quantities and considerably affect the physical-chemical composition of the disposal stacks;

d) sandstone with a diversified grain size, less susceptible to weathering;

e) gritstones very resistant to weathering;

f) calcacerous rocks occurring in small quantities, and

g) tuffites.

The size composition of the not overheated wastes is chiefly contributed by the stony skeleton. Owing to the weathering process the quantity of fine fractions increases, and is then leached out by water. During the storing operation the waste materials become scattered, placing itself so that the bottom layers chiefly contain coarse materials, and the top layers include first of all fine fractions. If the disposals contain considerable amounts of carbonaceous substances and show a porous structure facilitating gas exchange, a weathering of pyrites and heat emission take place, which in turn give rise to the oxidation of coal and contribute to a further increase in temperature. Under favorable conditions this thermal activity develops toward external parts of the disposal, to cause open fire. The burning process initiates a number of chemical reactions, which change the properties and composition of the rocks. The pH reaction of the stored materials also undergoes variations.

Recent disposals are characterized by a marked variation in pH reaction. This variation in a horizontal arrangement - owing to the effect of weathering and leaching - restores its equilibrium in a relatively short time, and in the vertical section undergoes slow changes. The high concentration of salts does not permit higher vegetation growth. The weathering of pyrites causes the acidification of the medium, caused by the formation of sulfuric acid transforming calcium carbonates into gypsum. The pH of the "soil" substrate is the resultant of weathering, desalination and acidification (2,5).

The nutrient content of the coal refuse depends on the thermal activity and age of the disposals, as well as on the processes mentioned above. P_2O_5 and N accumulation is low, whereas the K_2O content is satisfactory.

The properties of the power-plants' refuse depend both on the type of the coal fired and on the disposal method (7,8). Ashes from bituminous coal contain about 40 % of silicon dioxide, and considerable amounts of iron and aluminium oxides. The non-combustible coal varies from a few to several percents. The pH is strongly alkaline (12.8) and decreases with time. The nutrient content is low except for potassium. The salinity of ashes is high. Owing to the disadvantageous grain size, these wastes are characterized by decreased "water-air" and sorption properties (low ability to store water available for plant intakes). Ashes from lignite are more differentiated, as they depend on the calcium, magnesium and boron concentrations.

The properties of the ashes are chiefly responsible for the poor usability of these wastes in vegetation growth, which manifests in a sparse natural succession. The surfaces of the disposals are bare and highly susceptible to water and air erosion, until man interferes to improve these undesirable conditions.

FIRE PROTECTION

There is a number of methods for fire prevention in coal waste disposals or for the prophylaxis of fire control (1) . The methods listed below are amongst the most effective.

a) Surface covering of the centers of the open fire with a scaling clay layer (0.3 - 0.5 m thick) and a compaction of this layer.

b) Injection of the sealing pulp into cased holes 168 mm in dia.; the composition of pulp: water 56 %, dry components 44 % (including smoke-box dust 20 %, limestone dust 19.5 %, bentonite about 2.2 % and water-glass about 2.3 %); spacing of holes, one per 8.6 m^2 of the surface.

c) Injection of whitewash in 7 percent concentrations in pipes sunk into disposals with pile-drivers; spacing of pipes, one per 7 m^2 of the disposal surface; diam. of pipes, 52-80 mm.

d) Application of clayey mud, covering the crown top and slopes of the disposal, the sealing layer being 0.3 m thick, and that on the slopes 0.5 to 1.0 m thick; transport of pulp with rigid and flexible pipelines.

e) Compaction of waste with the use of heavy vibratory roller of VT-8 type on graded tops and on slopes (maximal slope gradient 1:5), and surface covering with 2-6 layers of waste material, each 0.4-1.0 m thick, with simultaneous compaction.

f) Gradual saturation of old conical disposals with whitewash using perforated pipes placed along the slopes of the disposals.

To protect newly formed disposals of wastes encumbered with coaly fractions, the methods described above and the sealing with clay or silt layers are employed.

DUSTING PROTECTION

To prevent secondary dust the following procedures are applied with variable success:

a) cover with film forming or binding substances,
b) biological consolidation,
c) combination of both methods.

The cover with film-forming or binding substances is based on the consolidation of surface through:

- spraying of film-forming substances such as asphalt emulsion, curasol, hüls, osacryl, oil-water emulsions, water solutions of elastomers;
- surface covering with a layer of mineral soil (fertile soil, sand, clay).

The biological methods used for this purpose are based on the consolidation of the disposal surfaces with herbaceous vegetation (usually perennial) or with woody species. Grasses and perennial legumes are most often grown on disposals.

Present-day recommendations involve biological methods in a combination with initial surface consolidation with film-producing substances, preventing dusting until the vegetation is fully developed.

A mechanical system was tested for spraying mixtures of consolidating emulsions, spreading mineral fertilizers and seeding seeds (hydraulically on pneumatically). Experimental studies on ash slope consolidation have revealed that the cover with grass mats, cut from lawns outside the disposal, yields the best results. A detailed discussion both of the treatment procedure and plant species selection is presented in a number of reports (2,3,5,7).

PRELIMINARY RECLAMATION

A reasonable management of the disposals depends first of all on the possibilities of productive soil creation and availability of the terrains for future users. If for example, a disposal situated high above the ground level does not meet the agricultural requirements it may be utilized as a recreational area (lawns, garden plots, sports). Large flat disposals seem to be most suitable for agricultural uses. If the reclaimed area contains large quantities of less fertile soil, it may be utilized for afforestation.

According Polish Standards preliminary reclamation for agricultural or forest utilization comprises (with reference to the new disposals) the following procedures:

a) removal of the top layers of fertile soil, or other potentially productive strata, from the areas to be occupied by disposals and a safe storage of this soil for the needs of future reclamation,

b) implementation of reclamation requirements as specified in chapter 2, during the construction and exploitation of the disposal and the storage of wastes in a manner ensuring a proper profile of the crown tops and slopes,

c) final grading of crown tops of all above-level and sublevel waste disposals and their slopes in a manner permitting their use in accordance with the determined direction of final utilization,

d) control of water conditions in the adjacent terrains in a manner ensuring an adequate level of the ground water table for the available utilization of these terrains,

e) utilization of top soils (as discussed in (a)) for the technological and biological consolidation of the slopes, and for the reproduction of soils on the crown tops,

f) reproduction of soils on the crown tops,

g) construction of the service road system

h) control of surface waters excess in accordance with the environment protection rules, to prevent contamination of the adjacent land.

The preliminary reclamation procedures should not be carried out without prior clearance with the future users and with the local Authorities.

The crown tops of the disposals are formed in a manner ensuring a gravitational run -off spring waters and storm waters or of waters drifted from the adjacent higher terrains if any. For this purpose, the surface is so arranged that the main draining ditches have a minimum gradient of 1-2 per mille, and particular drift faces are inclined in the direction of the draining ditches with a minimum gradient of 1-2 percent. The gradients in the micro-relief cannot exceed 10 % on agricultural land, and 15 % in forest type land. Low slopes of sublevel disposals, connecting the adjacent land, should be formed with a gradient of about 16 percent (1:6). The slope systems of the above-level disposals can be left without additional earth work, as it could cause a damage to the technological and biological consolidation.

The method of soil reproduction depends on the characteristics of the wastes. The disposals of inactive or weakly acid wastes, with a significant content of fine fractions may require an enrichment with organic matter and nutrients for the vegetation growth. Bottom ash and coal refuse characterized by decreased water-air and chemical properties may either need an insulation with fertile soil, or an enrichment with floating parts, to improve the ability of water storage and the sorption capacity, as well as the content of macro- and microelements. Most difficult for reclamation are strongly alkaline, saline ashes and the saline or strongly acidified coal wastes. The only effective method of reclamation is then the production of new cover soil through the insulation with a layer of fertile soil. This treatment procedure is very expensive. It is therefore advisable to minimize the thickness of the insulating layer. The results obtained in Poland, as well as in other European countries, show, that the minimal layer thickness required varies from 0.3 to 0.5 m for agricultural reclamation, and from 1.9 to 2.0 m for forest reclamation.

Larger thickness es are adopted for more toxic formations and in the in growth of vegetation less resistant to the influence of a toxic substance. This is to emphasize that for the needs of agricultural reclamation there are higher requirements regarding the quality of the insulating soil.

The surface drainage of the reclaimed disposals should be designed in a way which permit discharge the surface water at one point, to control the degree of pollution with toxic substances and suspended solids. If these substances occur in very high the superficial water should be subject either to a treatment procedure or to dilution. In the case of soil production with technical methods, or in the case of soil neutralization, the draining ditches should be conducted in a non-toxic medium.

SPECIFIC RECLAMATION

Specific reclamation is designed for agricultural and forest restoration and comprises the following procedures:

a) the control of hydrological conditions on the of the crown tops and slopes - where a necessity arises to perform additional operations following preliminary of elementary reclamation; for disposals erected above the ground level the construction of systems for both observation and adjustment of the ground water table according to the needs could be advised;

b) disposal (treatment) of toxic wastes (and particularly of ashes or alkaline deep mine wastes) with chemical and biological methods; these methods involve deconcentration of toxic substances by leaching, additions of humic soils, peats, or bentonite etc., pH changes by additions of acid materials; acid wastes are treated with lime or alkaline ashes etc.;

c) fertilization of the refuse with the use of organic, mineral or combined fertilizers, which contributes to the enrichment of the produced soils with organic substances and nutrients initiating and intensifying biochemical processes (supply of nitrogen, phosphorus, and other energy sources for microorganisms growth);

d) improvement of the physico-chemical and chemical properties of the refuse and of the insulating layers by the application of agro-meliorating treatment which increases the water and sorption capacities, and produced the required structure for the soils formed;

e) introduction of vegetation to reproduce the biological conditions on the crown tops and prevent wind and water erosion; it is recommended to introduce (during the first growth period) perennial legumes and grasses in mixtures;

f) supplementary biological or mechanical-biological consolidation of slopes together with their protection belts, utilizing their lining made during the disposal exploitation, also of the dykes of tailing ponds for high vegetation establishment; for planting of woody species one should use top-quality seedlings of trees and shrubs resistant to air pollution and sustaining the difficult soil conditions that occur on the on slopes, where a mechanical production of the soils is generally inhibited.

On the disposals already managed, as well as for the consolidation and the establishment of greenery or land reclamation for other purposes than agriculture and afforestation, any decision should be made in clearance with the user and local authorities.

A cheap method of temporary verdure planting on old conical disposals with steep slopes and on disposals endangered by thermal activity is to use vegetative of deciduous trees (3). Cuttings (sections of shoots of the parent tree, 18-25 cm long and 0.8-1.8 cm thick with few leaf buds) are planted with the aid of a sharp ended planter, and on the slopes (due to the sliding of the material) with the aid of shovels. Satisfactory results are obtained with poplar cuttings (Populus hybrida 275).

CONCLUSIONS

The correct the reclamation procedure depends chiefly on the method of soil reproduction. The application of an insulation layer of productive soil is very expensive but has the advantage of facilitating the neutralization and fertilization processes, and permits the introduction of a wide range of vegetation. Thus, there is an undoubtedly greater certainty that the reclamation will be effective.

The investigations on the reclamation of coal and of power-plants waste disposals point to greater possibilities of agricultural rather than of forest recultivation. It seems therefore advisable to assign the reclaimed arable land to the production of industrial vegetation only, until the toxic, substances contained in the refuse are rendered harmless to humans and animals.

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Some properties of mine wastes

Table 1

No.	Specification	Central Disposal Brzezinka	Central Disposal Bór-Zachód	Mine Szczygłowice (tailings+mine wastes)	
		Argillaceous schist after 4-6 years of weathering	Sandstone (not weathered)	Waste material (not weathered)	Waste material (weathered) (4-6 years)
1	Grain size (%):				
	1.0 mm	17.0	12.0	43	3 - 6
	1.0 mm				
	1.0-0.1 mm	37	60	56	67
	0.1-0.02 mm	14	11	14	13
	0.02 mm	49	29	30	20
2	pH (in KCl):	6.8-7.0	7.1-7.5	7.2-7.6	2.9-4.0
3	Salinity (mg NaCl/1 dm^3):	1.9-4.4	0.6-1.1	1.2-1.7	0.6
4	Content of organic (%):	10.6-11.9	11.5-12.5	9.0-31	7.8-12
5	Content of assimilable components:				
	- P_2O_5 after Egner (mg/100 g)	0.9-1.3	0.3-0.6	0.2-3.0	0.3-4.6
	- K_2O after Egner (mg/100 g)	42-49	33-40	0.9-5.4	6.5-9.0
	- Mg (mg/100 g)	35-52	12-15	33	35
6	Content of $CaCO_3$(%):	0.0-0.2	0.0-0.2	0	0
7	Content of microelements (ppm):				
	- B	4.8-14.5	1.7	2.0-2.7	0.6
	- CU	6.6- 9.1	8.0	7.7-8.3	7.4-9.1
	- Mn	8-14	3-4.5	0.6-0.9	3.9-4.7
	- Mo	0.2-0.3	0.04-0.09	0.3-0.4	0.10-0.14
	- Zn	12-17	10-13	4-57	7-9

Some properties of power industry wastes

Table 2

No.	Specification	Ashes from bituminous coal (Halemba Power Plant)	Ashes from lignite	
			Turów Power Plant	Konin Power Plant
1.	Grain size (%):			
	1 mm	2	0	2
	1 mm:			
	1.0–0.1 mm	37	8	36
	0.1–0.02 mm	37	76	36
	0.02 mm	26	16	28
2	pH (in KCl)	8.4–12.8	8.2	8.2–12.8
3	Salinity (mg NaCl/1dm^3):	0.8– 5.1	2.1	9.0
4	Content of assimilable components			
	- P_2O_5 - after Egner (mg/100 g)	94	6.2	0.7
	- K_2O - after Egner (mg/100 g)	19	30	55
	- Mg (mg/100 g)	13	27	60
5	Content of $CaCO_3$(%):	2.25	0.25	32
6	Content of microelements (ppm):			
	- B	48	7.75	20.5–35
	- Cu	20	12.3	0.0
	- Mn	0	8	8
	- Mo	0.6	2.0	0.2
	- Zn	32	13	0.5

SUCCESSFUL REVEGETATION OF COAL-MINED LANDS IN THE UNITED STATES

by

Willie R. Curtis [x/]

INTRODUCTION

Surface mining for coal in the United States began in Illinois just over 100 years ago. Natural revegetation of many of these areas probably began soon after mining ceased, because natural forces continually operate to vegetate disturbed land. For example, many of the 10- to 30-year-old coal surface mines in Alabama have been naturally reforested with loblolly pine and Virginia pine and now produce more commercial softwood timber than the surrounding unmined forest land (Lyle et. al. 1976).

Although some surface mines have been revegetated by natural means, the vegetation process can usually be hastened by planting. Among the earliest documented attempts at reclamation is the seeding of sweet clover on spoil-bank ridges by the Wayne Coal Company in Ohio as early as 1918 (Kohnke 1950). Tree planting followed in 1920, and several species of trees were planted on coal mine spoils in Illinois during that year. Reforestation of spoil banks was started in Pennsylvania as early as 1923. Then in 1929 research was started in Indiana to determine the adaptability of various tree species to conditions on spoil banks.

[x/] Willie R. Curtis, M.Sc. Hydrologist and Project Leader, Northeastern Forest Experiment Station Forest Service, U.S. Dep. Agriculture 370 Reed Road, Broomall, Pa. 19008.

RESEARCH

A formal research program on the forestation of strip-mined land was started in 1937 by the U.S. Forest Service through its Central States Forest Experiment Station at Columbus, Ohio (Lane 1968). Research was conducted in cooperation with the coal mining industry, state agencies, and agricultural experiment stations. The results of this early research were summarized by Limstrom (1960). It involved mostly the evaluation of survival and growth of many different tree species. The value of planting "nurse trees" such as black locust and European alder in mixture with other tree species received much attention. Limstrom's reasons and recommendations for planting the black locust are still valid. Successful forestation has been accomplished on thousands of acress of surface mined land through the use of species and planting procedures recommended by the research foresters. This early research still serves as the basis for many revegetation guides in use today.

Before the 1960s, most of the research and consequently most of the reclamation centered on tree species; there was little concern for erosion and sedimentation. Anyway, most of the sediment from erosion on the ungraded spoil piles was trapped in the valleys between these piles. Herbaceous cover was considered a hindrance to the establishment and growth of planted tree seedlings.

Beginning in the early 1960s more and more emphasis has been given to the quick establishment of herbaceous cover for erosion control and for aesthetic purposes. This new emphasis coincided with greatly expanded surface mining activity in the Appalachian region. Here, water runoff and erosion produce severe sedimentation problems. Subsequently, the use of herbaceous vegetation for ground cover and erosion control increased to the extent that for the past 10 year or so relatively few trees have been planted. Now it seems that the move is again toward planting of trees for more permanent cover. At the same time there is need for the quick cover of herbaceous species for erosion control. This has lead researchers to concentrate on simultaneous establishment of herbaceous cover and woody plants. Diversified plantings of grasses, legumes, shrubs, and tree species are still needed to provide for a variety of future uses of the land. Reforestation is anticipated as a result of natural plants succession in much of the eastern United States, especially where an herbaceous cover is established for erosion control without further management.

As early as the mid-1940s some research on the use of herbaceous species in reclamation was reported (Tyner and Smith 1945). Subsequent trials and other research have been conducted by the Forest Service, Soil Conservation Service, Agricultural Research Service, and various state experiment stations. The results of these experiments have been incorporated into revegetation guides published by Federal, State, and private agencies.

Many plantings have been made by industry-related groups such as reclamation associations and coal producers' associations, and by many individual mining companies. These plantings may also be used in evaluating reclamation success.

Almost everyone who engages in surface mine revegetation research begins with experiments related to the adaptability of species and varieties to spoil conditions at hand. Results often vary widely from area to area, even for the same species. If the spoils were described more specifically perhaps we could begin to understand the reasons for this. For example, spoil with a pH of 3.5 to 4.0 derived from one geologic formation may be no more toxic to plants than spoil with a pH of 4.5 derived from a different formation. Soil pH is often the only analysis reported and the implication is that particular plants will grow in all spoils of similar pH.

SOME FACTORS AFFECTING SUCCESSFUL REVEGETATION EFFORTS

Several of the more important factors that affect the successful establishment of vegetation on surface mine spoils will be discussed.

Seedbed preparation

That a suitable seedbed is necessary for the rapid and successful establishment of seeded vegetation on mine spoils was shown by Vogel (1974). On plots that were roto-tilled before seeding, vegetative cover was established faster and was more dense at the end of the first and second growing seasons than on plots that were not tilled. Tillage was more beneficial for seedings made between April 1 and October 15. The main advantage of tillage is that it breaks up the crust on the surface of the spoils and increases the number of micro-sites favorable for germination of seed and growth of the plants. Seeding on freshly graded spoils would provide the same advantages as tillage at lower cost.

Amendments

The amendments to be discussed are lime, fertilizer, and mulch.

Lime. The chemical properties that most often influence the establishment and growth of vegetation on strip-mine spoils are related to chemical reaction and imbalances in plant nutrients. Acidity or alkalinity is a very useful criterion for predicting the capacity of spoil to support vegetation. Its intensity is expressed as pH a measure of the concentration of hydrogen ions present. Most spoils in the eastern United States are in the acid range (below pH 7.0) while most spoil in the western states is alkaline.

Some plant species are more tolerant than others of acid conditions. Nearly all plant species will grow in spoils with a pH above 5.5. A more limited number will grow when pH is between 4.5 and 5.5 Fewer species can tolerate spoil below 4.5 and only a few will grow where pH is below 4.0. In the West, species tolerant of alkaline conditions must be selected.

There are other problems in establishing vegetation on acid spoils. Toxic levels of aluminium and manganese are soluble at low pHs and become harmful to plants. Roots of many plants will not grow into materials with toxic levels of soluble aluminium. Thus plant growth is stunted because the roots do not take up nutrients.

Some things can be done to ameliorate acid spoils. Amendments such as organic matter, fly ash, and topsoil may be added, but lime is the most used. Topsoiling is considered the most economical way of treating alkaline western spoils.

The most common practice now is to apply enough lime to raise pH to 5.5. At this pH, manganese and aluminium become less soluble and are no longer available in a form toxic to plants. Also phosphates and other nutrients become more readily available to plants.

Fertilizer. Most surface mine spoils are deficient in essential plant nutrients. Nitrogen is almost universally lacking; phosphorus is limited in most spoils but is adequate in some. Potassium generally is not limiting for the establishment of herbaceous vegetation.

A deficiency in nitrogen severely limits establishment and growth of herbaceous species, especially grass. Thus, the addition of nitrogen fertilizer is a must for successfully reclaiming mine spoils.

Further applications of nitrogen fertilizer may be avoided by planting or seeding nitrogen-fixing plant species. Legumes are used for this purpose, although the long-lived legumes usually take more than 1 year to get established. This means that annual legumes or grasses must be used for the initial quick cover needed to control erosion.

Mulches. Various mulches can be used during the critical period of seedling establishment to improve the microclimate and help conserve soil moisture. Among the many materials that have been tested for use on surface mine spoils are pulp fiber, grain straw, hay, wood chips, wood bark, leaves, and some chemical binders.

Generally wood pulp fiber is mixed with seed and fertilizer and applied with a hydroseeder. The amounts of this mulch usually used

(900-1100 kg/ha) are inadequate to significantly reduce erosion. Also, it is doubtful that they have a significant effect on moisture conservation.

Straw at 2200 to 3400 kg/ha, distributed evenly over the surface after seeding, can be a factor in the successful establishment of vegetation on spoils. However, it is often necessary to hold the straw in place with a binder or to run over it with a disc or crimper. Hay falls into the same category as straw. Both may retain seed which can result in a volunteer stand of vegetation. However, seed of some weeds may be undersirable.

Wood chips are good because they stay in place on the spoil. However, efforts to establish vegetation with wood chips as mulch have been disappointing.

Shredded tree bark applied at the rate of about 94 cubic meters per hectare has been found to be quite effective in conserving moisture, retarding runoff and erosion, and providing microclimatic conditions favorable to plant establishment and growth.

Leaves, too, have been found to be a valuable mulch. They can be applied with a blower or with a regular farm manure spreader. Leaves must be disced into the spoil to hold them in place.

Naturizer is a trade name of a mixture of composted municipal waste and sewage sludge. Initial tests indicate that reclaiming surface mine sites may be a beneficial way to dispose of these waste products.[1/]

Many chemical binding agents have been developed over the past few years and many of them are purported to work well in erosion control. Additional research is necessary to support those claims. When used alone these chemicals cannot serve all the same purposes as mulch; i.e., they cannot provide moisture conservation, stabilize the soil, and moderate surface temperature.

1/ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Sewage sludge and effluent have been used successfully in efforts to vegetate some problem spoils. Much research is underway at present into the use of these and other waste materials in reclamation.

Topsoiling is now required on nearly all surface mine disturbance in the United States. The so-called "topsoil" is removed from the area about to be mined and stockpiled for later spreading on the graded site. Almost all the unconsolidated overburden may be classed as topsoil. In many cases the importance of topsoiling cannot be disputed, but in some cases another stratum in the overburden may have more desirable characteristics for vegetating than the topsoil. In these cases the best material for plant growth should be placed on the surface.

Time of seeding

For a long time most seedings of mine spoil in the Appalachian region were made in the spring or fall, with spring generally being preferred. Many people believed that even in a humid region it was impossible to vegetate mine spoils by direct seeding in the summer. Vogel (1974) has shown that selected mixtures of temporary and long-lived herbaceous species can be used anytime between March 1 and October 15 in eastern Kentucky. Results of his study have been applied with success to other areas in the Appalachian region. Best initial cover was achieved during early spring and late fall with Balbo rye or annual ryegrass. Pearl millet, sudangrass-sorghum hybrid, and weeping lovegrass provided quickest cover from mid-May to mid-July. Kentucky-31 fescue and sericea lespedeza became the primary cover on the areas after two or three growing seasons.

In humid regions, barren areas should be seeded anytime mining is completed between March 1 and October 15. The seed mix can be changed to fit climatic conditions throughout this period. Seeding a temporary species for quick cover with the permanent species is desirable in most situations. The permanent species generally becomes established and replaces the temporary ones.

In any seeding, the species selected often is less important than adherence to good vegetation practices; i.e., preparation of a suitable seedbed, application of sufficient fertilizer, and, when necessary, application of lime and mulch.

In the Southwest it is important to seed when moisture conditions are best. For example, fourwing saltbush should be planted only when the probability of summer thunderstorms exceeds 50 percent and existing soil water stress is less than 2 atmospheres of tension.

Climate

The amount and distribution throughout the year of rainfall are strong factors in the establishment of vegetation. In the East rainfall is not usually a problem, but in the West and Southwest it may be the limiting factor in plant establishment. Supplemental water is recommended for areas that receive less than 200 mm of precipitation.

Species selection

Species of vegetation for use on surface mine spoils should be selected according to the time of year, type of spoil, purpose of seeding or planting, and the expected future use of the land.

One of the first considerations is to establish a quick cover for erosion control. This generally means a mixture of herbaceous annuals and perennials. Some woody species may be desirable. When temporary quick-cover species are mixed with permanent species, there is a chance that the temporary cover will prevent or retard the development of a satisfactory stand of the permanent cover. It is important to limit the amount of seed of the annual or quick-cover species to prevent this.

Many experiments have been conducted to determine the adaptability of various herbaceous and woody species for vegetating strip-mine spoils. Some species have been selected for their tolerance to acid conditions; others have been selected specifically for use on alkaline spoils. Many species of grasses are well suited to surface mine reclamation because they are adapted to a wide range of climatic and spoil conditions. Some species are desirable because germination is usually rapid and growth is quite good during the first growing season.

Many plant species have been tried with varying degrees of success in the United States. For each of the major coal producing regions there are preferred plant species in each of four major categories: grasses, forbs, shrubs, and trees. The grasses and forbs may be further classified as temporary, semi-permanent, or permanent. Temporary species are used to give quick cover for site protection; semi-permanent species are reasonably persistent perennials; permanent species are those expected to persist for many years.

Annual grasses can be used for quick cover and as companion crops with slower developing perennials. Some species are better adapted to spring seeding, others should be seeded in the summer, and still others in the fall.

Leguminous forbs are considered essential in ground-cover mixtures. Associated plants generally benefit from the nitrogen fixed by the legumes. Annual legumes germinate quickly and provide good cover within a few months. Perennial leguminous forbs often are more difficult to establish; many have hard seed coats or other specific dormancy requirements that delay germination. The availability of soil phosphorus is generally more critical for the establishment of legumes than for grasses. Seeding rates of companion grass species should be carefully regulated to prevent excessive competition and possible failure of the legumes. Each species of legumes must be inoculated with specific strains of Rhizobium bacteria to stimulate nodulation and to assure nitrogen fixing.

Shrubs for reclamation plantings have not been emphasized although they have significant value for site protection, wildlife food and cover, and aesthetics. Possibly in the future more emphasis will be placed on the use of shrubs.

Trees have generally been the mainstay of reclamation efforts. A few tree species can be directly seeded but most are normally established by planting seedlings. Many species are adapted to surface mine spoils, but species native to the area are usually recommended. Unfortunately, high value tree species are usually the most difficult to establish on spoils. Grass and legume ground covers generally reduce tree growth, at least in the early stages. In later years legumes may enhance growth. Black locust, autumn olive, and bristly locust are nitrogen fixers and can be beneficial as nurse trees for other tree species.

CURRENT PRACTICES

Revegetation practices in the U.S. are determined or influenced mainly by legal requirements. The seeding of grasses and herbaceous legumes to establish a cover for erosion control and for aesthetics is generally recommended. Thus, watershed protection automatically becomes the primary concern in land use. Once the herbaceous vegetation is well established it can be used for pasture and hay because species good for forage usually are used for vegetating mine spoils - for example, smooth bromegrass and alfalfa in Illinois and tall fescue and annual lespedeza in southern Appalachia. Livestock grazing is becoming common on vegetated strip mines even in the mountainous areas of Appalachia. Unfortunately, the tendency is to overgraze or start grazing before the vegetation is well established, which hinders the development of adequate cover.

The land use in effect at time of mining often influences the choice of revegetation practices. For example, prime agricultural land in the flatlands of Illinois is reclaimed for immediate return to row crop production.

On the other hand, forested land is usually not replanted to forest species. Some states require that woody species be planted in addition to the herbaceous species on steep slopes and other sites not intended for agricultural use. Normally the planting of woody species is optional for the landowner or mining company. The legal requirements in some states unintentionally discourage tree planting because they permit release of vegetation bonds as soon as the requirements for the herbaceous vegetative cover are met.

Black locust is still the most commonly used tree species. It is especially popular for use on steep slopes because it can be established by direct seeding in mixture with herbaceous species. Locust seedlings respond to fertilizer, especially phosphorus, as herbaceous legumes do, and first-year seedling heights of 30 cm or more are not uncommon. Unpopular "doghair" stands of locust sometimes develop where seeding rates are excessive. European black alder and autumn olive are other nitrogen-fixing woody plants that are used as nurse plants or site improvers and for wildlife habitat.

Red pine, white pine, and hybrid poplar have been successful in the northern Appalachian coal field. European white birch has been the most successful tree species on extremely acid spoils in Pennsylvania. Virginia pine has been widely planted in the middle and southern Appalachian region, and loblolly pine is often planted or direct-seeded in southern Appalachia. Most species of pine are tolerant of acid spoils, especially in association with the acid-tolerant mycorrhizal fungus *Pisolithus tinctorius* (Marx 1975).

Tree planting now is rare in the Midwest even though reforestation studies showed that high value hardwoods can be produced on spoils. This is due in part to political and social pressures that favor agricultural uses of all surface-mined lands. Also, hand planting of tree seedlings costs more and entails more labor-related problems than seeding of herbaceous species. Another reason for choosing agricultural uses over forestry is the greater and quicker economic return from the reclaimed land. Yet some of the 30- to 50-year-old hardwood stands, especially of black walnut, in Indiana and Illinois demonstrate the economic potential of growing forests on mined lands.

There is a need to establish a quick cover for erosion control at the same time that trees are planted, but the herbaceous vegetation may adversely affect survival and growth of the planted trees. Some people recommend seeding the herbaceous species one year and planting trees the next. Others suggest using herbicides to kill patches of herbaceous vegetation where tree seedlings will be planted.

A more practical method is to plant trees and herbaceous species at the same time. The herbaceous cover should consist mainly of legumes because the growth of trees usually is enhanced by legumes but is suppressed by grass (Vogel 1973). When seeding must be done in late spring and summer, and herbaceous cover can be established with summer annuals. These will die in the fall and provide a mulch over winter. Trees and perennial herbaceous species can be planted the following spring.

On areas that can be traversed with farm machinery, early competition of herbaceous species with trees can be avoided by planting the herbaceous species and trees in alternate strips. To further assure their establishment and early growth, tree seedlings should be inoculated with the appropriate mycorrhizal fungi (Marx 1975).

Revegetated surface mines can provide excellent wildlife habitat and water-based recreation, as is shown on many old strip mine sites. Present revegetation practices in the East often provide poor wildlife habitat because they use mainly a few species of grasses and legumes such as tall fescue and sericea lespedeza that provide little food or diversity of habitat.

SUMMARY

Several species of hardwoods and pines planted 30 years ago have been reasonably successful on spoils in both the Midwest and Appalachian coal fields. Especially encouraging is the success of high-value hardwoods such as black walnut, red oak, yellow poplar, and white pine. Many of the older strip mined lands are providing excellent wildlife habitat and water-based recreational uses.

Currently, most surface mines are being vegetated with herbaceous species to provide quick erosion control. Tree planting has been discouraged by economic, legal, and social pressures. Establishment of both trees and herbaceous cover is feasible especially be concurrent planting of tree seedlings and unaggressive herbaceous legumes.

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EFFORTS OF AGRICULTURAL RECLAMATION OF TOXIC SPOILS IN LIGNITE SURFACE MINING IN POLAND

by

Kazimierz Bauman[x/]

In surface mining of lignite in Poland the problem of agricultural recultivation of even toxic postindustrial soils is important owing to the lack of arable lands in relation to the demand for food products. This issue is particularly apparent with the lignite surface mine "Turów", where the spoil disposals will jointly comprise about 400 ha of land:

- external spoil disposals - about 2300 ha
- internal spoil disposals - about 1700 ha.

Due to the grading of the disposals, agricultural restoration is possible in almost the whole area of internal disposal and on the flat crowns of external disposal. One can assume that the conditions of proper grading of the disposals suitable for agricultural utilization will be met in an area of about 2000 ha.

The geological structure (3 coal beds), deep excavation (down to 200 m), and low quality of top soils on the area where external disposals were localized and the open pit ruled out the advisibility of selective removal of top soil for covering the surfaces of disposals. Approximate lithological composition of spoil material is as follows:

[x/] Kazimierz Bauman, M.Sc. eng. POLTEGOR, Rosenbergów 25, Wrocław.

Type of formations	Intercoal plys	Overburden over coal beds II and III
silts and clays	90 - 95 %	65 - 75 %
sands and gravels	5 - 10 %	15 - 20 %
coal plys	1 %	10 - 15 %

The content of essential components from an agricultural point of view is in spoil variable: nitrogen, phosphorus, calcium carbonate occur in very small amounts; potassium and magnesium in low or average amounts: microelements occur in average quantity: acidity of formations is high and variable - pH of quaternary formations is from 5.8 to 4.8, of tertiary formations from 5.1 to 3.0. A strong acid reaction is induced mainly by the presence of sulphuric acid produced largely by the effect of weathering compounds containing iron sulphates, pyrites, marcasites, hydroilites and others.

The overburden in respect of its usefulness for agricultural recultivation, using a 5-grade classification can be included mainly in the classes:

- D - bad soils, sterile, not fit for recultivation
- F - toxic soils

and to a small extent in the C class - of faulty soils, not suitable for agricultural recultivation, but fit for forest cultivation after partial improvement.

In such soil conditions nonselective removal and stacking of overburden is practised in Poland.

Neutralization and fertilization carried out in the course of reclamation is in such cases in use. This up-to-date practice is standard for the forest reclamation.

The positive effects of toxic soils reclamation in long-term research, the size of transformed terrains with active surface mines, and also the considerable anticipated development of surface mining created the need to start research on agricultural recultivation of this type of spoil disposals.

OBJECTIVE AND SCOPE OF RESEARCH

This up-to-date research carried out for the needs of reclamation was focussed on technology of the establishment of grass, legume and wood vegetation on toxic and sterile post mines terrains. In 1978 in cooperation with the US Environmental Protection Agency, detailed field tests on plants of higher agricultural utility started. It is the first so wide project on agricultural cultivation of cohesive and toxic soils. The basic objective of this research is the determination of the feasibility and profitability of agricultural cultivation in these types of soils. Field research performed in natural conditions will help to establish the most important elements of this problem, i.e.:

- the size of crops which is possible to obtain by different methods of early treatment of toxic and sterile terrains adopted for agricultural cultivation
- the quality of crops with particular attention to contents of chemical compounds harmful to humans and animals.

Experimental plots were set up on an external disposal of the lignite surface mine "Turów" on a fully graded part. Four groups of plots were established. The first group was set up on a terrain, on which in the years 1973-1975 grass and legumes under reclamation project were established.

Three other groups were set up on raw terrains not yet reclaimed-completely without vegetation growth.

In the first and second group of plots identical tillage will be performed and identical plants introduced. The aim of this part of research is to assess the extent to which earlier reclamation effects the results of vegetation cultivation.

On plots of the third and fourth groups organic substances regarded as incentive are applied additionally to initiate and intensify the soil producing processes. On the plots of the third group straw in a form of chaff was applied, and on plots of fourth group the sewage from local treatment plant was added. The object of this part of research is the determination of influence of the application of generally available organic substances on the effects of cultivation.

In order to compare the results obtained on plots set up on the un reclaimed soils the same neutralization was used as on plots of the first group and an additional compensating fertilization in the first year was applied. In the first year of research on plots of the first and second group the following species of plants were planted:

1. winter rye
2. winter wheat
3. spring barley
4. oats
5. sugar beetroots
6. late potatoes
7. corn
8. sunflower
9. broad-bean
10. pea

- on plots of the third and fourth group:

1. oats
2. spring barley
3. sugar beetroots
4. corn
5. pea.

In the second year of research, due to a very wet fall making impossible the performance of appropriate tillage treatments, seeding of winter crops was abandoned. Buckwheat and spring wheat were used instead. As an effect of observations made in the first year, sugar beetroots were substituted with fodder beetroots.

It is planned that in next years crops will be investigated in a typical agricultural crop rotation:

- root crops
- spring crops

- legume crops
- winter crops
- fodder crops.

The programmed observations anticipate the following operations:

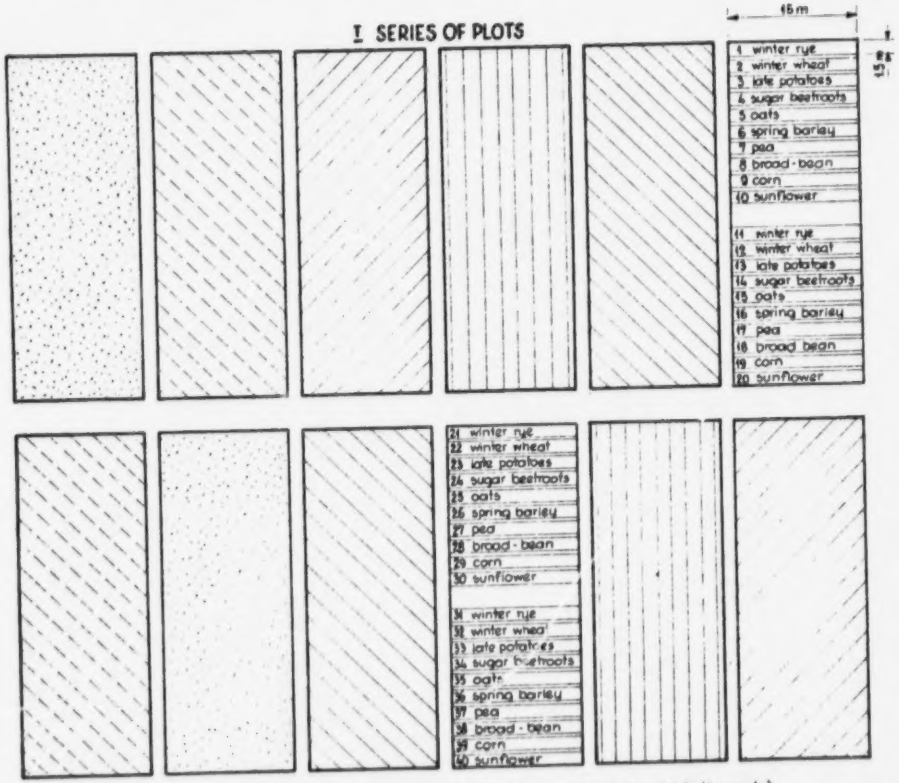
1. Observations of the growth and development of particular species of plants
2. Crop harvest and laboratory examination of their quality based on the designation of the following elements:
   - sprouting ability
   - mass of 1000 seeds
   - content of nourishing components: protein, fats, hydrocarbons, cellulose, ash and basic elements.
3. Soil sampling for laboratory analyses in the first year (at the beginning of investigations) and after the harvest of plants; in following years only after harvest.
4. Laboratory analyses of soil samples involve the designations:
   - of physical properties: mechanical composition, specific gravity and bulk density, porosity, water adherence ability, water capacity,
   - of chemical properties: pH reaction, content of organic carbon, macro- and microelements,
   - of biological properties: number of bacteria, of actinomyces, the the azotobacter occurrence, nitrification intensity and cellulose decomposition.

RESULTS OF TWO YEARS' RESEARCH

The plans of experimental plots are shown in figs. 1 and 2, which show also the general characteristics of habitat conditions, the doses of fertilizers, and crop rotation during the 2 years of experiments.

In table 1 levels of dust fall are shown and in table 2, the contents of some elements in dusts.

FIG. 1. PLAN OF EXPERIMENTAL PLOTS SET-UP ON TERRAINS PREVIOUSLY RECLAIMED


I SERIES OF PLOTS
15m
1.5
1 winter rye
2 winter wheat
3 late potatoes
4 sugar beetroots
5 oats
6 spring barley
7 pea
8 broad-bean
9 corn
10 sunflower
11 winter rye
12 winter wheat
13 late potatoes
14 sugar beetroots
15 oats
16 spring barley
17 pea
18 broad bean
19 corn
20 sunflower
21 winter rye
22 winter wheat
23 late potatoes
24 sugar beetroots
25 oats
26 spring barley
27 pea
28 broad-bean
29 corn
30 sunflower
31 winter rye
32 winter wheat
33 late potatoes
34 sugar beetroots
35 oats
36 spring barley
37 pea
38 broad-bean
39 corn
40 sunflower

▧ A ▨ B ▥ C ▤ D ▩ E ▧ F

Habitat conditions:

- flat terrain - crown of external disposal
- soils clayey with pH 3.5 - 4.5 in KCL,
- surface covering - 3 years growth of grasses,
- neutralization - lime in 0-15 cm layer in quantity of 5t/ha,
- ground phosphate rock in 15-30cm layer in quantity of 3t/ha.

Investigated crops:

1.- winter rye
2.- winter wheat
3.- spring barley
4.- oats
5.- sugar beetroots
6.- late potatoes
7.- corn
8.- sunflower
9.- broad - bean
10.- pea

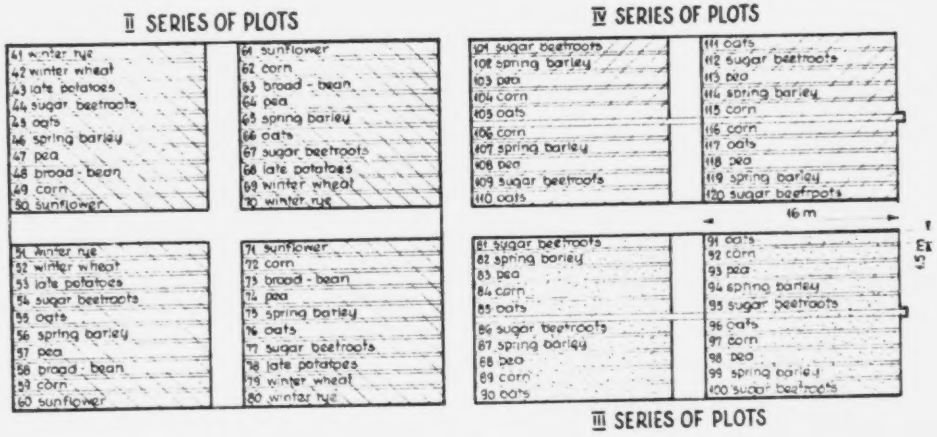
Crop rotation:

1. Beetroots 2. Cereals
3. Papilionaceae 4. Winter cereals
5. Fodder

Fertilization

N - 120 kg/ha N in doses of 40 kg/ha (presowing and outside the roots)
P - 200 kg/ha P_2O_5
K - 150 kg/ha K_2O

FIG. 2. PLAN OF EXPERIMENTAL PLOTS SET UP ON RACO TERRAINS WITHOUT RECLAMATION


II SERIES OF PLOTS
41 winter rye
42 winter wheat
43 late potatoes
44 sugar beetroots
45 oats
46 spring barley
47 pea
48 broad - bean
49 corn
50 sunflower
61 sunflower
62 corn
63 broad - bean
64 pea
65 spring barley
66 oats
67 sugar beetroots
68 late potatoes
69 winter wheat
70 winter rye
51 winter rye
52 winter wheat
53 late potatoes
54 sugar beetroots
55 oats
56 spring barley
57 pea
58 broad - bean
59 corn
60 sunflower
71 sunflower
72 corn
73 broad - bean
74 pea
75 spring barley
76 oats
77 sugar beetroots
78 late potatoes
79 winter wheat
80 winter rye
IV SERIES OF PLOTS
101 sugar beetroots
102 spring barley
103 pea
104 corn
105 oats
106 corn
107 spring barley
108 pea
109 sugar beetroots
110 oats
111 oats
112 sugar beetroots
113 pea
114 spring barley
115 corn
116 corn
117 oats
118 pea
119 spring barley
120 sugar beetroots
46 m
81 sugar beetroots
82 spring barley
83 pea
84 corn
85 oats
86 sugar beetroots
87 spring barley
88 pea
89 corn
90 oats
91 oats
92 corn
93 pea
94 spring barley
95 sugar beetroots
96 oats
97 corn
98 pea
99 spring barley
100 sugar beetroots
III SERIES OF PLOTS

Habitat conditions:
- flat terrain - of external disposal
- soils - clayey with pH 3,5 - 4,5 in KCl
- terrain surface with no vegetation
- neutralization - lime in layer 0-15 cm in quantity of 5t/ha
ground phosphate rock in layer 15-30 cm in quantity of 3t/ha

Investigated plants: I series the same as I series
III and IV series: 1. winter wheat
2. spring barley
3. sugar beetroot
4. corn 5. pea

Crop rotation:
- the same as in I series

Special treatments:
- III series - cereal straw cut as chaff in quantity of 10 t/ha
- IV series - sewage sediment in quantity of 50 t/ha

Fertilization:

II series the same as in series I
III and IV series N - 120 kg/ha - N
P - 200 kg/ha - P_2O_5
K - 150 kg/ha - K_2O

Apart from it on plots of II, III and IV series was applied compensatory fertilization to I series in quantities:

N - 92 kg/ha
P_2O_5 - 138 kg/ha
K_2O - 90 kg/ha

Fig. 3.

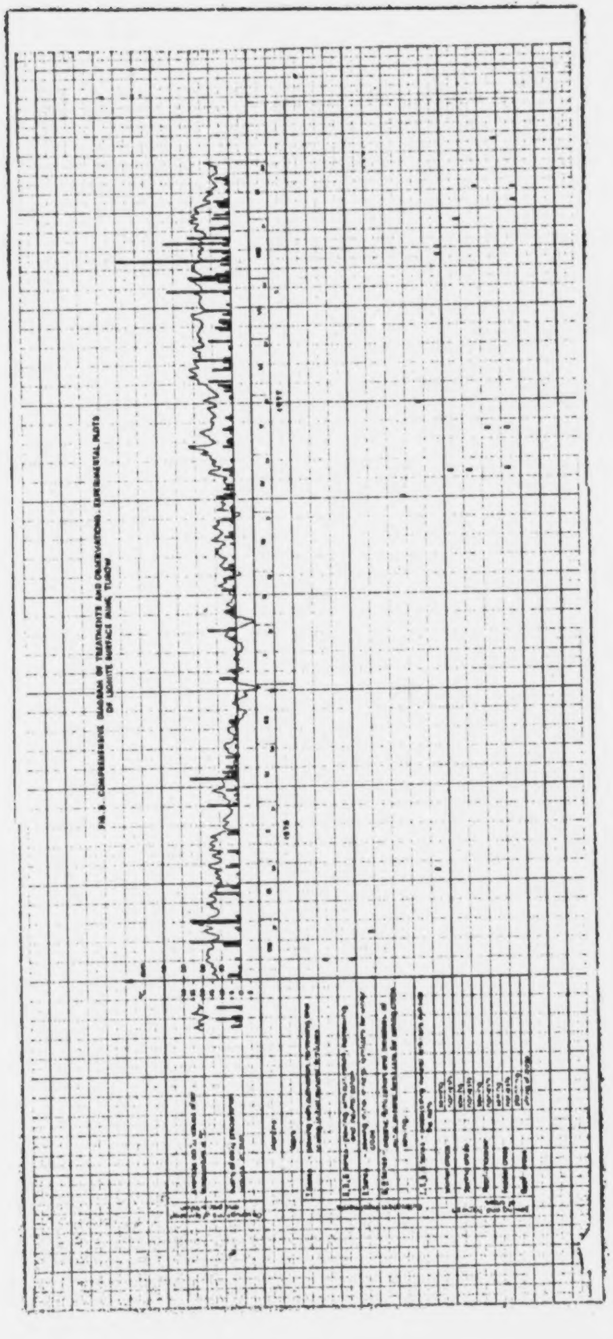


FIG. 3. COMPREHENSIVE DIAGRAM OF TREATMENTS AND OBSERVATIONS, EXPERIMENTAL PLOTS
OF LIGNITE SURFACE MINE, TUROW

DUST PRECIPITATION

Table No 1

Months		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Stand	Year	Monthly dust precipitation in t/km^2/month												
Turów Lignite Surface Mine	1973	104.7	10,9	65,1	78,6	46.7	25,5	47.8	19.0	18,4	24.0	42,8^{x}	26,2	509,3
	1974	41,7^{x}	42,5	66,6	29.1	53,3	39.3	26,6	73,2	32,9	19.7	32.9	42,3	500,1
	1975	20,4	27.1	9.7	4.7	20,9	39,8	31,4	35,7	21.3	24,9^{x}	37.6	33,0	306,5
	1976	40,9^{x}	32,9	41.2	36,3	49.5	41,4	37.3	44,1	41,0	30,4	47.3	48,9	491.2
	1977	48,2	15,6	104,4	62,2	44,1	58,0	45,5	147,2	43,1				
Bogatynia sewage treatment plant	1973	43,3	30,2	22,0	82,9	14.6	33,6	26,1	16,5	18,3	25,0	29,3^{x}	10.2	352,0
	1974	30,9	8,0	26,3	11,4	35,1	12,9	27,8	54,3	14,5	22,6	40,2	20,2	304,2
	1975	13,8	15,3^{x}	16,0	10,7	3,7	23,7	21,3	10.6	18,6	18,8	15,4	13,8	181.7
	1976	15,5	8.7	11,9	12,7	16,2	10.8	12,3	14,7	7,8	12,2	31.6	31.4	185,8
	1977	13,3	23,7	22,9	26,4	13,5	48,4	37.6	47.2	26,8				
Experimental plots	1977													
I		—	—	60.2	72,8		65,5	30,5	83,5	27,0	—	—	—	—
II				—	74,7	24,1	56,9	41.6	69,2	25,1	—	—	—	—

x - the sample average value taken from remaining months was adopted in table.

In fig. no. 3 a comprehensive diagram of treatments and observations is shown and in table no. 3, characteristics of atmospheric precipitation.

Table no. 2

Content of some elements in precipitated dust

Ord. no.	Specification	Content in mg/g of sample
1	Sodium	27.117.7
2	Potassium	26.601.3
3	Zinc	3.964.6
4	Copper	165.5
5	Calcium	32.071.2
6	Iron	35.234.2
7	Magnesium	13.284.8
8	Lithium	133.4
9	Manganese	727.4
10	Strontium	126.6
11	Chromium	120.0
12	Cadmium	70.7

QUANTITY AND QUALITY OF CROPS

The quality of crops of plants in the first year of tests were low. Almost all species gave much lower harvests than the ones from normal cultivation fields. Some species were not even harvested due to the low numbers of plants growing on plots. Such as pea and sugar beet, which were collected only from 2 plots of the no. 4 series.

Some species such as the winter rye gave a relatively high harvest close to average harvest level in the country. The value of the crops and some of their qualitative parameters will be discussed successively for each species.

Table no. 3

Precipitation amounts typical values for the meteorological station in Bogatynia

Time period	Sums of precipitation in mm	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Values for years 1949–1972	average	34.3	39.0	38.5	57.5	79.5	84.9	95.4	74.4	57.5	48.2	39.6	44.7	693.5
	maximum	75.8	99.7	81.0	108.8	170.0	192.0	197.9	150.8	218.7	136.5	75.3	97.8	930.1
	minimum	7.3	11.9	12.0	10.7	27.5	13.1	25.1	35.6	1.9	2.8	3.6	5.9	479.2

Winter rye

Year 1977

Rye gave better yields on experimental plots of no. 1 series. The harvest amounting to 27.8 q/ha of grain and 36.4 q/ha of straw has to be considered as very good. Particular attention is drawn to the considerable ability of rye to germinate up to 96 and 94 %. By this ability to germinate, the grain so obtained from these plots can be used as sowing material. The content of nutritious components and elements does not deviate from average contents obtained in standard agricultural experiments. Favourable also is the ratio of grain yields to straw yield. It approaches normal and amounts to 1.3 for no. 1 series, and 2.3 for no. 2 series.

In 1978 the winter rye was not sown out.

Winter and spring wheat

Year	Variety	Grain in q/ha				Straw q/ha			
		Plot series				Plot series			
		I	II	III	IV	I	II	III	IV
1977	Winter wheat	4.7	8.60			12.40	24.30		
1978	Spring wheat	19.50	12	8	16	42	48	41	46

Year 1977

Crop of wheat was very low, to compare with standard fields of discussed region where the Grana variety gives from 40 to 60 q/ha. The ability to germinate was also very low and this grain was not suitable for sowing. With wheat as with rye, the high content of ash in the straw occurred. Also high was the content of protein in the straw in the experiment of no. 1 series. The remaining elements were within normal limits.

Year 1978

Crops were higher. Differences in grain yields between plots were as anticipated - highest on plots previously reclaimed, and on plots with addition of sewage. The yields of straw show no such relationship.

Oats

Year	Grain q/ha				Straw q/ha			
	Plot series				Plot series			
	I	II	III	IV	I	II	III	IV
1977	15.00	4.20	4.00	6.30	24.50	16.50	17.60	24.10
1978	33.00	20.00	-	-	57.00	48.00	-	-

Year 1977

The crop of oats in the 1-st series was much higher than in second and third series. In fourth series the crop was little higher than in no.2 and 3 series. Crops of oats under standard conditions are in this area a (30-60 q/ha) number of times higher than the ones obtained from tests. Attention is drawn to the low ability of germination of acquired grain and a relatively high content of fibrine caused by a high content of husks in the crop. The other parameters were normal for oats.

Year 1978

The yield of oats was considerably higher, one may even regard it as very good.
The lack of results of quality analyses does not allow the full assessment of acquired crops.

Spring barley

Year	Grain q/ha				Straw q/ha			
	plot series				plot series			
	I	II	III	IV	I	II	III	IV
1977	8.60	-	-	16.50	12.40	-	-	22.40
1978	20.00	15.00	14.00	11.00	35.00	42.00	25.00	35.00

Year 1977

Crops of barley were low, particularly in first series. Barley of the variety Aramir in this region normally gives crops from 40-70 q/ha. Germination ability of grain acquired from experimental plots was quite high and reached (particularly in fourth series) the level of 90 %. The grain obtained from the first series had a low ability to germinate. The other parameters were within average limits for spring barley.

Year 1978

The crops were higher although continued to be lower than the ones obtained on normal arable lands.

Pea

Year	Seeds		Straw	
	plot series		plot series	
	I	II	I	II
1977	-	-	-	-
1978	8.00	8.50	16.00	13.00

In 1977 peas was not gathered due to the loss of too many plants. In 1978 the promised yield was very good. The results acquired after harvest differed from expectations, due to considerable uncontrolled consumption by random passers-by.

Broadbean

Year	Seeds plot series		Straw plot series	
	I	II	I	II
1977	16.50	7.40	24.20	15.80

Crops of broadbean were quite low and of low ability to germinate. Harvest of broadbean from normal fields in this area at reaches a level of 20-30 q/ha of seeds and about 40-60 q/ha of straw. Content of protein in seeds of the second series was also lower than average-amounting to about 30 %. The other parameters were at a normal level, staying within average values, for the standards production of broadbeans.

Year 1978

The crops have not yet been harvested. The first phase of plant development was very promising. Lack of pesticides application during flowering period caused practically total destruction of seeds.

Sugar beet

In 1977 crops of sugar beetroots were diversified. On Plots of the fourth series the crops were: the roots - 245 q/ha, leaves - 260 kg/ha. On remaining plots the size of beetroots was very small: the diameter ranged from 2 to 5 cm, with a large portion smaller still.

In 1978 fodder beet roots were sown. The crops do not seem to be very good. In small local depressions -often filled with rain water - the root seeds did not germinate, or perished in the later development phase.

Potatoes

Crops of potatoes in 1977 on plots of first series were 122 q/ha to compare with the average crops on a national production scale, which in 1977 was 203 q/ha. However the crops in second series II amounted to 12 q/ha which was much less than the planting norm.

Corn (maize) and Sunflower

Year 1977

The cron and the sunflower did not attain their full development level. The corn was collected when still at the grain filling, and part also at the phase of wax-milk ripeness. The sunflower was harvested at the time when a part of the growing fruit was completely ripe and part was still in florescence. Therefore only the harvest of whole corn plants was specified and for sunflower the crop of seeds from the ripened fruitification. For corn the crop of green mass from the first series amounted to 380 q/ha with a content of 23 % dry mass, and from the remaining series no crop was gathered due to great losses of plants on the plots. The crop of sunflower seeds amounted to 4.2 q/ha, which makes about 20 percent of normal production in this region.

Year 1978

The crops this year will be similar as last year's

QUALITATIVE CHANGES IN SOIL CONDITIONS

To investigate changes that occur in soil due to the effect of reclamation work carried out on it as well as fertilization, and cultivation of vegetation, samples of soil were taken from each series of the plots in autumn (Sep. 16. 1977). Particular attention was drawn to the chemical and of microbiological properties, as these characteristics differentiate themselves more quickly than any other soil characteristics.

Mechanical, physical and water characteristics did not differ at all from the ones determined in spring. In chemical properties attention was drawn to the continuing considerable soil acidity, the small reserve of nitrogen, and lack of $CaCo_3$. Addition of straw (third series) and of sewage (fourth series) effected small increases in phosphorus reserves. In all series of experiments the content of potassium decreased, while the content of magnesium was unchanged. Content of microelements did not undergo any greater changes, fluctuations were small and within normal limits.

Content of some microelements and microbiological activity of soils after one year of experiments - determinations being made in surface layer of 0-20 cm

Ord. No.	Specification	Units	Series 1	Series 2	Series 3	Series 4
1.	Content of Cu	ppm	17	22	26	43
2.	Content of Pb	ppm	33	35	22	81
3.	Content of Mn	ppm	201	348	357	248
4.	Content of Ni	ppm	13	17	22	17
5.	Content of Zn	ppm	138	170	215	128
6.	Bacterium rank number	millions	6.9	8.7	10.7	10.6
7.	Actinomyces	thousands	480	400	320	300
8.	Fungi	"	lack	lack	lack	lack
9.	Auotobacter	"	lack	lack	lack	lack
10.	Decomposition of cellulose	% loss	80	30	30	70

Microbiological activity of soils increased quite conspicuously, particularly in series 3 and series 4 where the amount of bacteria increased 3 times in comparison with the spring season, and as well as the decomposition of cellulose, the intensity of which rose about 7-fold.

CONCLUSIONS

The first year of research provided certain information data regarding the orientation of further research work on agricultural economic restoration of spoil disposal of the lignite surface mine Turow. The changes which should be introduced in the second year of study concern the selection of plant species, the norms of sowing, the fertilization doses, the soil sampling for laboratory analyses, and the scope of laboratory designations.

In the selection of the plant species, winter crops will be replaced by spring cereal plants. This change was effected due to the unfavourable weather occurring in the fall of 1977, that prevented the performance of preparatory work and the sowing of winter crops. In the following year the expediency of a resumed introduction of winter crops should be considered. In place of sugar beet fodder beet will be introduced. This change is necessary as the roots of sugar beet don't develop properly, due to the subsoil being too compacted at a depth of about 20 cm, which causes furcation of roots. Introduction of fodder beet that develop roots above the surface soil, with only a small portion growing in the soil, would be a better solution.

For soil conditions occurring in the experimental plots the quotas of sowing material should be increased. This goes both for the cereal and for legumes. The quotas of sowing should be increased by some 20 percent. The increase in the quantity of seeding material ensues from the fact that not all seeds sprout after germinating, besides the cereal plants spread less than in normal soils.

The level of fertilization should be increased to 200 kg/ha of N, 200 kg/ha of P_2O_5 and to 200 kg/ha of K_2O values. Reserves of basic nourishing components in soil were very low, therefore the fertilization should be increased to such a level as to provide basic nutrients for the plants and for micro-organisms present in the soil.

The method of soil sampling for laboratory analyses should be changed. Due to considerable soil heterogeneity the number of sampling points is to be increased, especially for the layer of 0-20 cm. The surface layer undergoes the action, strongest, with these transformations taking place in it being the most intensive. The determination of changes occurring in this layer will be possible when the number of points of soil sampled for analysis will increase. Increasing the number of points will decrease the incidence of heterogeneity in designations of laboratory results.

In next years the expediency of soil liming is to be considered in order to change soil acidity, should the results of the second year of tests vouch for such an expediency.

ENVIRONMENTAL CONSEQUENCES OF COAL MINING - EASTERN UNITED STATES

by

Scott C. McPhilliamy x/

INTRODUCTION

Coal mine operations in the United States have been ongoing probably since the mid 1700's. References to coal were made as early as 1672. One early active coal mine operation was reported in Pittsburgh, Pennsylvania in 1760. Since the date of these early exploitations, the coal industry has expanded to the point where more than 6,000 active mines produced 685 million tons of coal in 1977. The ratio of the number of surface mines to underground mines is approximately 60:40 while production also favors surface mines in the ratio of 55:45 (surface: underground).

The coal fields of the United States are generally divided into three distinct geographical areas. They are: eastern, midwest and western fields. The eastern fields may be further subdivided into the bituminous and anthracite fields. In 1976 coal production was reported in 26 states. West Virginia and Kentucky are the largest eastern field producers, Illinois is the leading midwest producer, and Wyoming and Montana are the largest western producers. Production figures for the eastern coal field states are shown on Table I, by mining method for the years 1970-1976.

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x/ Scott C. McPhilliamy - Environmentalist. Environmental Protection Agency, Region III. Wheeling Field Office, Wheeling, W.VA.

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The western coal field areas of the United States are rapidly expanding and large production increases are expected. A National Coal Association study has projected that the western operations will account for approximately two-thirds of new coal production in the U.S. In contrast, underground mining will be the main source of new coal production (aapproximately 75 %) in the eastern U.S.

EASTERN COAL EXTRACTION

Todays discussion of the environmental consequences of coal mining will be limited to the eastern coal field areas. This area is commonly referred to as the Appalachian coal field. Although small areas of the eastern coal fields lie outside the boundaries of Appalachia (notably in Ohio) and the Appalachian boundaries include areas of no coal deposition, the areas are sufficiently similiar to be used interchangeably for todays discussion. Coal is the most abundant mineral resource in Appalachia and about 70 percent of total cumulative production in the United States has been from this area. Coal deposits underlie more then 185,000 square kilometers, about 40 percent of the total Appalachia region. The coal strata are generally flat to gently dipping with occasional steepening. There are approximately 90 mineable seams, of which 60 may be surface mined, depending on local conditions and equipment. The sulfur content of the coal ranges from 0.5 to 6 percent.

In general, topographic features of the eastern coal field areas can be classified as hilly or rolling in contrast to the relatively flat terrain of the midwest or western coal fields. Consequently contour mining, auger mining and mountain top mining have been the predominate surface methods used to mine the steeply sloping coal areas. Approximately 50 % of Appalachian coal production is from areas exhibiting slopes in excess of 20 degrees. Modified mining techniques have also been adapted to areas with rolling terrains. Underground mining techniques include drift, slope, and shaft methods for coal extraction.

ENVIRONMENTAL CONSEQUENCES

The environmental consequences of both surface and underground mining are readily apparent throughout the eastern coal field areas. Past mining operations were planned and developed to minimize the cost of coal production and transportation with little or no regard for pollution control. Water pollution problems related to coal mine operations were apparent prior to 1900. The earliest recorded references to degraded water quality in coal mining areas were made by communities and industries which utilized such streams for water supply. Fish kills due to acid mine drainage were reported as early as 1890 in Pennsylvania. By the early 1930's the problem of mine drainage had grown to such magnitude that the Federal Government authorized a program of sealing worked-out underground coal mines to prevent or reduce acid mine drainage. For example, in West Virginia it was reported that 3,644 mine openings were sealed. Initial evaluation of the mine sealing program was quite favorable. However, the outbreak of World War II saw the abandonment of the program and the loss of opportunity for subsequent evaluation of the sealing programs as an abatement technique. Many of the sealed mines were put back into production during the war and no maintenance was provided for the undisturbed seals. As a result, much of whatever benefit was achieved has been lost.

In general, the stream water pollution problems resulting from both surface and underground mining operations are most apparent in the eastern coal field areas of the U.S. It has been estimated that 16,800 kilometers of Appalachian streams are affected by coal mine drainage pollution, 10,700 kilometers of these on a continuous basis. The mine drainage pollution of these streams probably qualifies as the most significant pollution problem in terms of the severity of damage to streams and in terms of the effort and cost that will be required to abate this pollution. Approximately 80 percent of acid pollution comes from abandoned or inactive mines and over 70 percent originates in underground mines. There are entire river basin systems (as large as 10,000 sq. km.) where nearly all major streams within the basin have been degraded due to the deleterious effects of acid mine drainage. It is not uncommon for coal mines to continue the production of acid mine drainage even though the operations may have been abandoned in excess of 100 years. Relatively small amounts of acid mine drainage can prevent the use of surface waters for some recreational uses as well as for fish and aquatic life production.

Table II present a summary of mine drainage pollution in the subbasin areas of Appalachia.

During the period 1930 - 1971, approximately 610,000 hectares of land was surface mined for coal in the United States. Approximately two-thirds of this affected land area occurred in the eastern United States. Varying degrees of reclamation were conducted on about 60 percent of this eastern land area. Coal surface mine operations presently mine about 600 hectares per week in the United States. Although little comparison can be made between past and present surface minign practices, the eastern U.S. has inherited a residual problem of thousands of hectares of unreclaimed or inadequately reclaimed surface mined area. Due to the generally steep slopes encountered in the eastern U.S., coal has historically been surface mined by methods which have allowed the downslope deposition of spoil material and permitted highwalls to remain intact. Although such mining practices are no longer allowed, the earlier use of such practices have been responsible for significant aesthetic and environmental problems which will require massive post mining reclamation efforts. It is noteworthy that the prohibiting of outslope spoil deposition and highwalls are rather recent modifications of standard surface mining practices. It has been estimated that 32,000 kilometers of highwall and 2,700 kilometers of massive landslide outslope exist in the Appalachian coal field states.

There is no complete inventory or listing of abandoned or inactive underground coal mines in the United States. Conservatively, this number is estimated in excess of 68,000 such sites. The number of estimated sites for all underground mineral mining is in excess of 90,000. The more serious adverse environmental effects resulting from under-

TABLE II

MINE DRAINAGE POLLUTION IN APPALACHIA

Subarea in Appalachia	Drainage Area (sq. km)	Kilometers of Polluted Streams			Unreclaimed Surface Mine Land (hectares)
		Intermittently	Continuously	Total	
Anthracite Region (Susquehana and Delaware)	10,878	564	419	983	34,000
Tioga	7,252	32	56	88	1,600
West Branch Susquehana	17,871	966	869	1835	29,000
Juniata	8,806	32	97	129	8,300
North Branch Potomac	5,698	64	209	273	2,000
Allegheny	30,380	140	1576	1716	32,000
Monongahela	19,166	465	2225	2690	32,000
Beaver	3,885	64	109	173	8,100
Muskingum	11,240	174	666	840	12,000
Hocking	3,108	227	359	586	1,600
Little Kanawha	5,957	40	8	48	1,600
Kanawha	31,857	876	1383	2259	26,000
Scioto	5,957	13	-	13	400
Guyandotte	4,325	18	464	482	4,400
Big Sandy	11,137	712	93	805	12,500
Ohio and Minor Tributaries	32,634	267	1874	2141	19,000
Kentucky	11,655	692	105	797	4,000
Cumberland	28,101	491	330	821	12,000
Tennessee-Black Warrior	72,520	250	-	250	7,500
		6,087	10,842	16,929	248,000

ground mining include: (1) damage to surface and structures from subsidence: (2) water pollution: (3) accumulations of solid waste: (4) burning refuse banks: and (5) fires in abandoned mines and in virgin coal deposits.

An estimated 81,000 hectares of land has subsided following underground mining. However, the majority of this subsidence has occurred under forest, agricultural, or idle lands.

Coal preparation plants are faced with the problem of disposing of millions of tons of rock and mining debris, much of which is combustible. This material is usually directed to a common dump which creates a sizable refuse bank. Fires are started in these banks by human carelessness, spontaneous combustion, or freak accidents of nature. Once ignited such banks may burn for years or even decades, polluting the atmosphere with smoke and noxious gases. Such fires are extinguishable only at great expense. More than 200 such fires were reported in the U.S. during a survey conducted about eight years ago.

Fires in abandoned coal mines and in virgin coal deposits cause air pollution, promote surface subsidence by burning out the support for overlying strata, and destroy valuable fuel reserves. As early as 1776, a coal bed fire was reported in Pennsylvania and remained active until at least 1846 (last reported date). In New Straitsville, Ohio and underground mine fire was ignited in 1884 and continues to burn today in an isolated area under a relatively thin rock and earth cover. During the 1930's over one million dollars was spent at this site constructing incomustible barriers but failed to effect control. In a U.S. Bureau of Mines study, 131 uncontrolled underground mine fires and 106 fires in virgin coal seams were reported. On an overall basis, no single program approach or technique can be used to effectively abate or control acid mine drainage. A wide range of technology exists that enables withdrawal users of water to adjust to acid mine drainage. This technology includes water treatment, the substitution of materials and processes to reduce the effects of acid, and the use of alternative sources. Similiarly, a wide variety of techniques is available that can be used to reduce the amount of acid drainage pollution in surface waters. These pollution control measures include land reclamation and stabilization, drainage diversion, sealing of underground mines and water treatment.

The choice of pollution control techniques depends on the type of mining source producing the pollution - whether it is active or inactive, the geologic and hydrologic characteristics of the mine, anticipated secondary effects, and the expected water quality improvement. Some techniques are relatively inexpensive, such as land reclamation and drainage diversion. Since only a small amount of the total acid drainage problem (10-12 %) emanates from surface sources, only limited water quality improvements can be achieved by using land reclamation and drainage control techniques. Consequently, significant results can be realized in only small areas. Other pollution control techniques that prevent acid formation are generally quite costly, highly dependent upon suitable geologic and hydrologic conditions, and less predictable in their effectiveness.

As a result, the practical methods available for pollution control at many sites are usually limited in number, relatively expensive, uncertain in their predictability, and do not produce uniformly acceptable results. Unfortunately, such sites are often the ones producing significant amounts of pollution.

FEDERAL AND STATE ENVIRONMENTAL LEGISLATION

During the late 1930's and early 1940's several of the major coal producing states began to enact surface mine legislation. The first of these states to pass such legislation was West Virginia in 1939, soon followed by Indiana in 1941. By this time the adverse environmental consequences (both actual and potential) of surface mining were becoming more and more apparent. Such legislation was necessary to hopefully minimize future environmental damages and to help insure that existing problems did not grow in magnitude. However, the requirements of such early legislative actions were quite minimal by todays standards and serious environmental damages occurred even after the early attempts of legislative control. Alabama was the last of the Appalachian states to pass surface mine legislation in 1970. Amendments to the original acts were passed in all the Appalachian coal field states by 1977.

In 1977, the Surface Mining Control and Reclamation Act was passed. This act is administered by the U.S. Department of Interior. This was the first nationwide surface mining legislation enacted in the United States. Under this act performance standards for surface mines were established. Such standards involve restoring mined lands so these lands can support their original uses, minimizing hydrologic disturbances, maintaining and then removing waste piles when they are no longer used, and establishing permanent vegetative cover after the site is restored to its original contour. The operator is responsible for successful vegetation on the affected area for a period of five years if the operation is located in a region where the average annual precipitation is greater than 66 cm, and for 10 years in a region with less than 66 cm of average annual precipitation. These standards are to be implemented by states through their own regulatory programs approved by the federal government or by the federal government in states that do not develop approvable programs. Permits for minign are to be issued requiring maximum coal utilization, stabilizing areas and waste piles to control erosion, treatment of acid-forming and toxic materials, construction of water impoundments and reclamation of abandoned areas to minimize long-term environmental effects of mining activities. Another facet of the law is that if prior to the initiation of mining an area is deemed not reclaimable, the regulatory authority may designate the area unsuitable for mining.

In addition, special performance standards are applicable for mining on steep slopes, mountain top removal operations, and mining on prime farm lands. Special provisions are also included for coal mines in Alaska, anthracite mines in Pennsylvania and some bituminous coal mines in Wyoming.

The ability of coal operators to comply with the federal regulations will vary with the individual states. Prior to the federal program the individual states had no uniform reclamation standards. States such as Ohio and West Virginia enacted stringent reclamation laws prior to passage of the federal requirements. As a result these states will have much less difficulty complying with the nationwide performance standards than will the states which had minimal requirements.

The Federal Water Pollution Control Act of 1972, as amended, was responsible for the development of effluent guidelines reflecting best practical treatment technology for all industrial categories. Such criteria were developed for the coal industry. The development criteria included the industry as a whole, i.e. surface mines, underground mines and coal preparation plants.

The effluent guidelines developed for the coal industry under the Federal Water Pollution Control Act and the Surface Mining Control and Reclamation Act, in combination, provide for the first uniform and nationwide comprehensive program for environmental control of the coal industry.

It should be noted that the effluent criteria developed for the coal industry, which are presently applicable, represent minimum requirements. The individual states have the alternative of adopting standards even more restrictive than the federal requirements.

State requirements for mine water discharges from active surface mines in the eastern U.S. range from a minimum of pH control in Virginia to the more stringent control required by Tennessee. In Tennessee the controlled parameters include pH, total iron, settleable solids, suspended solids, manganese, and sulfate. In general, state programs have been developed to control pH, iron and solids.

As mentioned above, present federal effluent limitations are applicable to both surface and underground coal operations. The requirements were initially developed by the U.S. Environmental Protection Agency and have now been adopted by the Office of Surface Mining. The present limitations are shown below.

Effluent Characteristic	Daily Maximum Value	Daily Average Value
Manganese	4 mg/l	2 mg/l
Total Suspended Solids	70 mg/l	35 mg/l
Total Iron	7 mg/l	3.5 mg/l
pH	within 6.0 - 9.0 range	

The surface mine operator is required to direct all surface water coming from a disturbed area through a sedimentation pond, or a series of ponds, prior to discharge to the receiving stream. These discharges must achieve compliance with all applicable state requirements in addition to meeting the minimum federal effluent limitations listed above.

Any overflow from the disturbed area resulting from a precipitation event larger than a 10 year, 24 hour frequency are exempted from the effluent limitations. However, if the pH value of the normally discharged effluent exhibits a pH value less than 6.0, then an approved neutralization process must be installed. All operators must maintain an approved water monitoring program that will provide adequate information on the daily and seasonal variation in discharges in terms of flow rate, pH, total iron, manganese, and suspended solids. The data must then be reported within 60 days of collection.

Mine drainage neutralization facilities are common throughout the coal fields of the eastern U.S. Such facilities may treat from less than 20 liters per minute to more than four thousand liters per minute. The larger of such facilities are associated with underground mines.

FUNDS FOR ENVIRONMENTAL PROTECTION

Hopefully, existing federal and state mining regulations relating to environmental protection are now adequate to prevent further degradation. However, it is the residual problem of abandoned and unreclaimed mine lands which will require major, remedial work in future years. The problem of highly acid discharges from abandoned underground mines will undoubtedly be the major challenge which must be addressed before any complete mined land remedial program can be accomplished.

A number of the eastern states have established special funds for the purpose of abandoned mine reclamation. Generally the source of these funds are from fines imposed on operators for violations of mining procedures and from bond forfitures. West Virginia, however, was the first state to develop a special reclamation fund for the specific purpose of reclaiming lands which have been mined but not reclaimed in accordance with modern standards. The West Virginia program was initiated in 1963 when an aerial survey revealed there were nearly 50,000 hectares of unreclaimed or inadequately reclaimed lands within the state. Under this program every coal operator was required to pay the Department of Natural Resources a fee of $ 150.00 per hectare for each hectare from which overburden was to be removed. To date, this program has reclaimed more than 10,000 hectares. Most of the reclamation work is conducted by a Soil Conservation District, a private reclamation contractor, or by a mining company that is operating in the area. In addition to the Special Reclamation Fund, the present day trend toward "restripping" or mining areas that were previously mined is having a significant impact on the reduction of orphaned lands. With this increase in restripping, over 150 linear kilometers of old highwalls have been eliminated since 1975. These areas are reclaimed under present day standards.

In 1967, Pennsylvania authorized $ 500 million for a Land and Water Conservation and Reclamation Fund. This fund specifically allocated $ 200 million for the elimination of land and water scars created by past coal mining practices. To date, more than 400 projects have been completed with expenditures in excess of $ 75 million.

Until the present, mined land reclamation and water pollution control projects have been limited to state programs or to federal demonstration projects which have been limited to small geographical areas.

One of the unique aspects of the Surface Mining Control and Reclamation Act is the stablishment of the Abandoned Mine Reclamation Fund. This capital will provide for land and water reclamation, for acquisition of unreclaimed lands and for research and demonstration projects on reclaiming abandoned lands. The fund is primarily derived from fees of 35 ¢/ton of surface mined coal, 15¢ /ton of underground mined coal, and 10¢/ton of lignite. User fees on reclaimed lands and funds from the sale of reclaimed lands are also deposited in the fund. Based on past coal production information, it is estimated that $140 million will be collected during the first program year.

The State of West Virginia anticipates receipt of $10 million per year from this program in order to correct past coal mining abuses on orphaned land program will equal all the money that was generated during the past fourteen years by the State's Special Reclamation Fund. Similiar funds are available to all other states where remedial actions are required.

SUMMARY

Todays discussion has touched briefly on some of the environmental problems, and their causes, associated with the coal industry. Todays discussion has touched briefly on some of the environmental problems, and their causes, associated with the coal industry. Todays problems are generally the aftermath of a mining philosophy which was not required to consider the long term environmental consequences of coal mining. Today, such practices have been discontinued and uniform minimum performance standards have been adopted for the industry. For the first time the United States has the mechanisms by which the ongoing operations are required to consider environmental issues during normal daily operating procedures which will help to insure no additional environmental problems while at the same time action has been initiated to correct past environmental damages.

TABLE I

EASTERN STATES COAL PRODUCTION 1970 - 1971[1/] (million tons)

	1970		1971		1972		1973		1974		1975		1976	
	Surface	Underground	Surface	Underground	Surface	Underground	Surface	Underground	Surface	Underground	Surface	Underground	Surface	Underground
Alabama	11,482	9,078	11,194	6,751	13,226	7,588	11,613	7,616	12,771	7,053	15,030	7,614	14,200	7,400
Kentucky	62,695	62,610	66,172	53,216	64,693	56,494	64,750	62,895	73,700	63,497	77,981	65,632	75,900	64,100
Maryland	1,377	238	1,467	176	1,500	141	1,722	66	2,247	90	N/A	N/A	2,500	0,18
Ohio	37,240	18,111	38,568	12,862	34,698	16,269	29,558	16,225	31,045	14,365	31,315	15,455	29,300	16,200
Pennsylvania	25,108	55,382	28,546	44,289	28,806	49,133	30,195	46,207	38,213	42,249	39,506	44,631	39,900	43,800
Tennessee	3,886	4,350	5,728	3,543	5,394	5,886	4,584	3,636	4,435	3,106	4,400	3,806	4,200	4,100
Virginia	6,998	28,018	8,997	21,631	10,035	23,993	10,524	23,437	11,559	22,767	12,329	23,181	12,800	24,000
West Virginia	27,657	116,414	25,821	92,437	22,080	101,662	19,932	95,516	20,243	82,220	20,926	88,357	21,000	87,800

1/ From NCA *Coal Data* Publication

SELECTED PROBLEMS OF ENVIRONMENTAL PROTECTION IN DESIGNING COAL FIRED POWER - PLANTS AND HIGH TENSION SYSTEMS

by

Jerzy Kucowski[x/]

INTRODUCTION

The prevailng position of conventional coal fired power plants in Polish power industry, cause that much of attention nowadays is devoted to environmental problems connected with these facilities.

These are the problems:

- pollution of air and land with dust (fly ash) and gaseous compounds (chiefly SO_2), entrained in furnace gases escaping through the power plant chimney stacks
- secondary environmental pollution with solid waste products
- impact on soil and water
- effect of noise
- influence of cooling towers and ventilators
- influence of power industry facilities on landscape changes
- influence of high tension systems.

The most serious of the above cited problems are pollution of air and land and the impact on water, (especially water heating). Therefore most attention is devoted to those problems, especially to the air and land pollution control. Increasing investment expenses for environ-

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[x/] Jerzy Kucowski, M.Sc. - Chief Engineer ENERGOPROJEKT-Warsaw, Krucza 12

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mental protection have been planned for construction of new plants as well as for the modernization of working ones with the aim to minimize the harmful influence on environmental. Development of this activity is essential for the continuous fast development of power production. One should emphasize the fact that quality of coal fired in Polish power plants is not the best, and the trend of its further deterioration in the last few years is evident. There is more and more lignite fired in Polish power plants too. Basic parameters of coal fired in Polish power plants is illustrated by the following table:

		Bituminous coal		Lignite
		I Rank	II Rank	-
Calorific value	k cal/kg	4700-5000	3500-4300	1600-2100
Ash	%	20-25	20-35	10-27
Moisture	%	10-12	15-30	45-55
Sulphur	%	0.8-1.2	1.1-2.8	0.6-1.1

Problems of environmental protection are broadly considered just in designing power plants fired with coal and high tension power systems. Environmental factors also strongly affect location of new power plants and considerably determine technological solutions. Only three following subjects have been discussed in this paper:

- chimney stacks of power plants
- utilization of lakes as cooling circuits with respect to environment protection aspects
- high tension systems design from the forest protection point of view.

CHIMNEY STACKS OF POWER PLANTS

In the Polish power industry as in other countries which use conventional power fuel, one of the basic solutions for limiting atmospheric pollution by sulphur dioxide is up to now the construction of stacks - as high as 300 m.

Calculations and measurements indicated that use of the greatest possible concentration of power per single chimney stack is essential i.e. by adding of a large number of boilers to one stack. It can be illustrated by the case of a 2000 MW power plant where application of one chimney stack 300 m high to the whole power plant gives 2 to 3 times less $S0_2$ emission as compared to the application of two or three stacks of the same height. However the adoption of a chimney stack with one conduit is not advisable in this case. More advisable is use of a multi-conduit stack.

Multi-conduit chimney stacks for power plants have been constructed in many countries such as England, Austria, France, Japan, Canada, Hungary, East and West Germany, Sweden, and the Soviet Union. This construction has been also introduced in Poland.

The advantages of multi-conduit chimney stacks are as follows:

- concentration of a great mass of furnace gases in one point which gas a fundamental impact on thermal uplift, and thereby, on the better dispersion of gases and on the decrease of the concentration of pollutants,
- avoidance of gases being scrubbed by the retention of high outlet velocity from particular conduits,
- establishment and unification of the conditions of furnace gases flow independently of the number of boilers in use or their of engagement,
- possibility of better control of waste gases flow (pollution, velocity),
- possibility of a succesive link-up of particular conduits as the power plant develops,
- after the erection of a ferroconcrete external shaft there is the possibility to continue the work inside, without the necessity of forming a protection zone around the chimney,
- possibility of easy visual control and repairs of particular conduits during exploitation time (including replacementof particular segments),
- avoidance of switching off a great number of blocks,

- smaller cost as compared with a few one-conduit chimneys (A one-conduit collecting stack, with a number of boilers connected to it is cheaper, but does not have the above advantages of a multi-conduit stack).

Drawbacks of multi-conduit chimney stacks are:

- more complicated construction (several elements require very careful execution),
- difficulty in acquisition of appropriate ceramic materials for the conduits of boiler gases,
- eventual necessity to employ stainless steel for conduits of gases or difficulties of adequate prevention of carbon steel corrosion (when the design involves).

From the above considerations it appears that multi-conduit chimney stacks have their advantages and disadvantages. However this is to emphasize that in countries, in which this construction, was used very exact and universal analyses were performed which showed its usefulness. Similarly, in Poland the complex optimizing analysis (elaborated by the "Energoprojekt" with contributions from specialistic agencies engaged in designing of chimney stacks) was carried out.

In this analysis many variants were elaborated, assuming that the requirements of the Polish standards, regarding air pollution, will be met. Single conduit stacks were compared with multiconduit stacks. Taken into account among other things were investment costs, feasibility of execution, exploitation costs and reliability of the power plant work.

The results of analysis confirmed the advisability and the feasibility of the construction of multi-conduit chimney stacks in our conditions.

Several chimney stacks of this type, have been erected in Poland and further ones are in construction or on the drawing board. These are the chimneys 150 to 300 m high with the number of conduits from 3 to 6. External shafts of chimneys are in ferroconcrete, and internal conduits in steel or in ceramic.

In the designs of new power plants and of heat and power generating plants, the construction of multi-conduit chimney stacks is usually anticipated.

UTILIZATION OF LAKES IN COOLING CIRCUITS OF THERMAL POWER PLANTS

The problem of lakes' utilization in cooling circuits of power plants will be discussed in an example of a complex of power plants with joint rating 2200 MW, fired with lignite.

The lakes used to cool the water of these power plants were subjected to wide investigations of changes, affected by heat, in physicochemical water composition, and in biological life.

Results of these tests helped to determine the influence of such cooling systems on the water medium of lakes.

The natural water reservoir, used to cool the water there, consists of 5 lakes with total surface area about 13.0 km^2, and total volume 66 million m^3 of water.

The lakes have their own watershed with 411 km^2 area, in which surface mines of lignite are located. Water is drawn to the lakes from the drainages of these mines in amounts of about 3.0 m^3/sec. Some drainage is discharged to the nearby flowing river.

The circulation of the cooled water, due to interdependent positioning of the lakes, is very complicated. The realization of coaling circuits required the construction of about 30 km of canals, 5 pumping stations and a number of water intakes and offtakes. The most important elements in the problem of environmental protection are discharge points of cooling water to the lakes, and the canals taking warm water from the power plant.

Biological investigations have shown that in heated lakes more intensive development of all forms of life, of flora and fauna ocurred. The effect of water heating was most evident on the composition of the fish species and their habitat.

Warming of water in lakes did not eliminate any fish species such as living prior to the cooling circuit of power plants being put to work. All species were preserved, however a clear change in quantitative relations of particular species was noted. The increase of water temperature greatly affected the growth rate of all fish species. Particularly large increases were noted in case of the herbivorous fish these fishes weight increased from two to twenty times depending on the fish specie.

Investigations of fish resistance to high temperatures of water indicated that average lethal temperatures dependent on fish species varied from 34.5°C to 40.6°C, and alarm temperatures from 28.5°C to 34.5°C.

The only dinstinctly negative effect the for fish cultures was more frequent occurrence of parasites.

The performed studies enable further conclusions also.

Thermal load, determined as the average value for the whole area of lakes may be:

- for summer months up to 160 kcal/m^2/h
- for winter months up to 400 kcal/m^2/h.

Particular lakes of the whole complex or separate parts of lakes in the region of canal discharges may be loaded up to the 200 kcal/m^2/h in summer.

Water temperatures in relation to the values observed in normal conditions may increase:

- on the average by about 7°C
- in summer months by about 5°C
- in winter months by about 10°C.

Maximum temperatures of the water from the power plant in points of its discharge to the lakes should not exceed 35°C. Average monthly temperatures of the water calculated as average values for the whole area of lakes should not exceed 28.5°C.

Design of cooling circuts should anticipate construction of canals (which draw warm water from power plants) of possibly large surfaces. The water should be introduced to the lakes by the overflows with a small unitry water flow. Velocity of the water in direct offtakes from the canals should not exceed 0.2 m/sec.

Lakes used for water cooling should be under rational fish culture systemto maintain the balance in biological life, and to avoid disturbances in exploitation of cooling circuits. Finally it should be emphasized that the investigations were carried out, on models and in the field, by "Energoprojekt" - Warsaw. Under the "Energoprojekt" direction, the Institute of Meteorology and Water Management has performed long-term observations and tests of the thermal balance of lakes, of phisical and chemical properties of water and of flora and fauna.

The Institute of Fish Cultures investigated the behaviour of ichtiofauna under the influence of warm water and experimented on the feasibility of warmth liking herbivorous fish cultures.

The results of the research indicated the lack of a real negative influence of heating on lake water ecosystem. A positive effect of this heating on fish cultures has been stated.

DESIGN OF HIGH TENSION SYSTEMS FROM THE FOREST PROTECTION POINT OF VIEW

Economic development of the country, and environmental protection problems provide also difficulties in the construction of power lines' routes.

The network of lines of 110 kV, 220 kV and 400 kV voltage is presently much longer than the total length of rail lines in Poland, and it increases annual by about 1000 km. Power lines frequently collide with various elements such as for instance a forest where a glade should be cut through. Low suspended power lines with large spacing between wires are more advantageous for power industry becouse of the smaller cost of installation and greater operational certainty. However, such lines cause more collisions with various elements and require wider forest glades.

Taking these factors into account the overhead lines of 110 kV, 220 kV and 400 kV have been designed by "Energoprojekt" on the poles with narrow construction. Minimum width of the line was achieved by substituting of horizontal or triangular arrangement of the wires with a vertical arrangement. In the case of the double circuit overhead lines introduction of insulator strings in "V" arrangement additionally decreases the line width. This helps to decrease the width of forest glades, and thereby save many hectares of the forest which is very important for national economy and for environmental protection too.

The decrease of the forest glade width by application of the poles of narrow construction have been listed below:

Voltage	Circuit numbers	Width of a glade		Difference between normal and narrowed glades	
		for normal poles construction	for narrow poles construction		
kV	pieces	m	m	m	per cent
110	1	13.8	7.3	6.5	47
110	2	14.1	10.2	3.9.	28
220	1	23.2	8.0	15.2	65
220	2	27.0	14.3	12.7	47
400	1	31.4	10.8	20.6	66
400	2	27.1	20.5	6.6	24

Application of narrow construction poles saves annually about 70 ha of forest.

The further research stage aiming at greater decrease of the width of forest glades is the preparation of a working plan for the lines suspended on the poles above the forest. For example if a 400 kV line in normal design requires to remove trees in a 31.4 m wide belt, and a narrow construction line on 10.8 m wide belt, then the line suspended on the poles above the forest can limit this glade to the width of 6 m. Moreover the two first solutions require removing of single tall trees situated on the edges of the glades to prevent their possible falling on the wires, while in the over-forest line case such thing can not happen. Therefore over-forest-lines are very advantageous for forest protection. However, they also have certain disadvantages i.e. worse operation certainty, greater thunderbolt hazard, higher cost, longer time of construction. Because of these disadwantages one does not expect a universal use of the over-forest-lines. Besides, one has to note that construction of the lines suspended on the poles as high as 60 m or more, is not every where possible. There will be constructed experimental sectors of such line in aim to test in practice all its advantages and drawbacks. It has been anticipated, that over-forest-lines will be in the first place used in cases of absolute necessity such as preservation of compact forest stands, or of unique trees or trees monuments of Nature, and also there where no other route is possible.

THE IMPACTS OF COAL EXTRACTION AND CONVERSION ON AIR QUALITY - AND CONTROL MEASURES THEREFORE

by

Terry L. Thoem[x/]

INTRODUCTION

It is apparent to all of us that the demand for energy resource development continues to increase. Vast coal reserves in the Western United States provide an attractive option for meeting this demand. Approximately 650 million tons of coal were mined in the United States in 1976 of which about 450 million tons were used in steam electric generating plants. Of this total about 70 million tons were mined in the six Region VIII states of Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming. This figure of 70 million tons is projected to go to 300 million tons by 1985 at the same time that the U.S. supply is projected to go to slightly in excess of 1 billion tons. A tripling of fossil fuel fired generating capacity from 1977 to 1985 (10 thousand megawatts to 30 thousand megawatts) is in store for the Region VIII states. Coupling this increase in coal mining and combustion in the Region VIII States with a concern as expressed in the Clean Air Act Amendments of 1977 for information on health effects of arsenic, cadmium, Polycylic Organic Material, and certain radioactive pollutants places a demand on trace element data collection. With some foresight, Region VIII EPA has been funding research in order to provide trace element emissions data. In addition to the expressed concern over these

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[x/] Terry L. Thoem, Deputy Director, Office of Energy, Environmental Protection Agency, Denver, Colorado.

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trace element emissions from coal conversion, research programs have attempted to define the amount of particulate matter which will be introduced into the atmosphere as a result of surface coal mining activities.

This paper attempts to summarize the results of these field research programs with particular emphasis on the power plant trace element emissions.

CONCLUSIONS

Conclusions which may be reached from the results of these research programs are...

1. Good emission control practices are necessary and are available to prevent significant air quality degradation from mining activities.
2. Coal conversion results in the release of certain toxic trace elements. A number of these trace elements are preferentially enriched in the fly ash/flue gas stream. Also, the enrichment of certain trace elements may be characterized as a function of particle size.
3. The magnitude of enrichment and hence release to the atmosphere is significantly dependent upon whether the trace elements is associated with the inorganic or organic phase of the coal.
4. The magnitude of trace element emissions is dependent upon the concentration in the coal, the particulate control device collection efficiency, and the control device operating temperature.
5. Although there are variations in trace element concentrations in coal a general conclusion can be reached that Western coal exhibits less trace elements per BTU than midwestern coal.
6. Although it was expected that hot side electrostatic precipitators would be poorer trace element collectors than cold side precipitators, results provided mixed conclusions depending upon the specific element of interest.

DISCUSSION OF TRACE ELEMENT PROGRAMS

1975 Program

The combustion process produces a wide variety of emissions and effluents ranging from sulfur and nitrogen oxides and particulates in the flue gas to solid and liquid wastes. In addition to carbonaceous material, coal contains inorganic matter in the form of mineral inclusions in the coal which become part of the emissions and effluents from the generating station. The distribution of this material among the effluent streams of a generating station is dictated by 1) the coal composition, 2) station boiler configuration, and 3) the flue gas particulate control devices utilized.

The 1975 study described the detailed characterization of 27 inorganic elements in the flows around three coal-fired steam generating stations. The three stations include examples of two boiler designs - tangentially fired and cyclonic; and three flue gas particulate control techniques-venturi scrubber, electrostatic precipitator, and mechanical cyclones.

Materials and Methods

The sampling scheme for each of the stations was designed to collect representative samples and mass flow rate data for each incoming and exiting material stream. The three stations operated at relatively constant boiler load during the sampling periods, thus approximating steady state conditions. Therefore, long-term averaging of samples and flow rates were not required to obtain representative data.

Plant Descriptions

Station I consists of four individual units with a total generating capacity of 750 MW fired with Wyoming sub-bituminous coal. Unit No. 4 was sampled for this program. This unit is a tangentially-fired, balanced draft 330 MW boiler with three venturi scrubbers for particulate emission control.

Station II has a 350 MW tangentially fired boiler using Wyoming sub-bituminous coal. A hot-side electrostatic precipitator provides fly ash control.

A North Dakota lignite is fired in a 250 MW cyclonic boiler with mechanical cyclone particulate collectors at Station III.

Sampling Techniques

All incoming and exiting streams at each plant were sampled concurrently over a two-day period. Fly ash in the exiting flue gas was collected using wet electrostatic precipitator (WEP) sampling devices. The collection efficiency of this device was found to be 99+% when compared to the recommended EPA filter technique. The capacility of long-term sampling and excellent sample recovery coupled with its high collection efficiency make this sampling technique especially suitable for trace element determination in the flue gas.

Solid, liquid, and slurry streams were sampled periodically during the sampling period. The individual solid samples were combined and representative portions obtained by random splitting either by quartering or with riffle buckets. Composite samples of the solids and liquids in slurry streams were obtained by combining the individual samples and separation of solids and liquids by filtration. Composite samples of liquid streams were also obtained by combination of the individual samples. Liquid samples were acidified to prevent absorption of trace constituents on the walls of the polypropylene containers during storage.

Analytical Strategy

The samples were quantitatively analyzed for 27 trace and minor inorganic elements. These analyses were based on five general techniques:

(1) atomic absorption spectroscopy (Ag, Cr, Hg, Al, Mg, Fe, Ca, V, As, Mn, Cu, Zn, Co, Be, Pb, Mo, Cd, Sb, Ni);

(2) X-ray fluorescence (Ba);

(3) ion selective electrodes (Cl, F);

(4) fluorometry (U, Se); and

(5) colorimetry (Ti, B).

Four general sample types were encountered at the three plants:

(1) coal,
(2) coal ash and sludge,
(3) lime, and
(4) aqueous, including WEP liquor.

Semiquantitative analyses were performed by spark source mass spectrometry (SSMS) for 53 elements, including the 27 analyzed quantitatively. Due to several limitations of the techniques, the results of SSMS survey analyses generally agree only within an order of magnitude with the quantitative results.

Flow Rates

The mass flow rate of each stream was determined either by direct measurement, from plant operating data or from material balance expressions for total mass flow or mass flow of a major consituent.

From the analytical results and mass flow rate determinations, mass flows for each element in each plant stream were calculated. These data were used as input to trace element material balance expressions.

Results and Discussion

As previously mentioned, it was found that the quantity of an element leaving a generating station in each of the various exiting ash streams is dependent on its concentration in the coal, boiler configuration and load, flue gas emission control devices employed, and the properties of the element and its compounds.

The first factor, i.e., concentration in coal is a function of the type and source of coal. The last three factors influence the fractional distribution among the various exiting ash streams. The distribution of the total ash among these streams is dictated by the boiler configuration and the collection efficiency of the flue gas particulate control devices.

Coal Ash Distribution

The trace and minor constituents entering the power stations with the coal are distributed among the following exit ash streams:

(1) fly ash or vapor phase in the flue gas;

(2) bottom ash;

(3) scrubber ash (Station I), precipitator ash (Station II), or cyclone ash (Station III).

In all three cases, the economizer ash was an extremely small stream. It was combined with bottom ash at Station II because the two were sluiced together with pyrites from the mills and separate samples were not available.

The tangentially-fired boilers at Stations I and II produce approximately the same portion (20 percent) of bottom ash. The cyclonic boiler at Station III yields significantly more bottom ash (65 percent) as is common with this burner design. This separation between bottom ash and fly ash leaving the boiler is the first significant point of fractionation of the coal ash the accompanying elements. The second major fractionation comes at the flue gas particulate control devices. Stations I and II are again comparable at this point. The venturi wet scrubbers at Station I and the hot-side electrostatic precipitators at Station II exhibit collection efficiencies for the fly ash of 99.6 % and 99.1 %, respectively. The mechanical cyclone collectors at Station III retain approximately 85 % of the fly ash leaving the boiler with the flue gas.

Element Distributions

The majority of the trace and minor elements contained in coal are associated with the mineral matter which forms the major portion of the coal ash. This association with mineral matter or with the carbonaceous portion of the coal was further investigated in the 1977 program. Unless some mechanism produces a selective partition of the elements during one of the major fractionations of the ash, the elements would be distributed among the ash streams in the same proportion as the total ash. However, from the examination of the data, it became evident that many of the elements are enriched in the flue gas and fly ash and correspondingly depleted in other streams.

Fly ash in the Flue Gas

It was found that enrichment in the flue gas at all three stations (arsenic at two of the three stations) is indicated for:

sulfur
mercury
chlorine
antimony
fluorine
selenium
vanadium
lead
molybdenum
nickel
boron
zinc
cadium
chromium
copper
cobalt
uranium
arsenic
silver

The remainder of the elements exit the stack in the same proportions as the ash. These include:

barium
beryllium
iron
aluminium
calcium
titanium
manganese
magnesium

Bottom Ash

At all of the stations, the bottom ash was sluiced to settling ponds. During sluicing some of the elements are leached from the ash by the sluice water.

The fractions of the elements in the scrubber ash (Station I), precipitator ash (Station II) and cyclone ash (Station III) are similar to the total ash fractions for most of the elements. Sulfur, mercury and chlorine are markedly depleted in these ash streams. These three elements appear to be leaving the stations predominantly as gaseous species.

Enrichment mechanism

The enrichment of certain elements in the fly ash and flue gas of the various stations can be partially explained by the volatilization of these elements or their compounds in the fire box of the boiler. The volatilization provides the mechanism for the selective partitioning of elements during the fractionation of the ash between fly ash and bottom ash. The volatilized elements or their compounds can subsequently;

(1) remain gaseous,
(2) recondense partially, or
(3) recondense completaly.

In the first case a high percentage of an element incoming with the coal will be discharged through the stack unless the flue gas control devices are designed for their collection. This behavior seems to be exhibited by the elements sulfur, mercury, and chlorine.

Partial or complete condensation will lead to an increase in the concentration of these elements in the fine particulate fraction of the fly ash. Condensation can occur by nucleation or deposition on available surfaces. At the relatively low residence times between volatilization and condensation, any nucleation that occurs will result in small particles. Deposition on the fly ash particles will be surface area dependent. This also will result in increased concentrations in the small particulates due to their greater specific surface area. This trace element concentration dependence on the fly ash particle size has also been observed by other researchers.

1977 Program

In order to further investigate the fly ash trace element enrichment concept and mechanism two coal fired power plants were sampled in 1977. Coal analyses were made and fly ash samples were collected as a function of particle size. The two facilities differed in the placement of their electrostatic precipitators relative to the combustion air preheaters. The hot-side (HS) precipitator operated on a gas stream with temperature of 830°F. The cold side (CS) precipitator gas temperature was about 250°F.

Fly ash was collected at each plant by three methods:

- High volume (5ACFM) source assessment sampling system cyclones,
- Low volume (1ACFM) cyclones, and
- Anderson cascade impactor

A wet electrostatic precipitator served as the secondary collector for fine particulates escaping the primary collector.

Sample Analyses

Samples of coal and fly ash were analyzed for 15 elements:

arsenic
beryllium
calcium
cadmium
chromium
copper
fluorine
mercury
manganese
nickel
lead
selenium
titanium
uranium
zinc

Analytical techniques employed were:

- flame atomic absorption (Hg, Be, Cr, Cu, Zn, Ca, Mn)
- flameless atomic absorption (Cd, Pb, Ni, As)

- specific ion electrode (F)
- fluorometry, (Se, U) and,
- colorimetry (Ti).

Coal samples were crushed to 200 mesh and separated into sink and float fractions using mixtures of benzene and carbon tetrachloride to provide separation liquor specific gravities of 1.35 and 1.45.

Some preliminary organic analyses were performed using the gas chromatography-mass spectrometry technique. Concentrations of organics in the flue gas stream were extremely low.

Results and Discussion

It was hypothesized that if an element was strongly associated with the organic portion of coal it would tend to be strongly enriched in the flue gas because of the tendency to form a vapor or fine particle metal oxide. The sink float results as presented in Table 1 were plotted as illustrated in figure 1. Extrapolations to 0 and 100 percent ash content were used to define the percent of association of a trace element with the inorganic and organic phase. The preliminary reports tend to indicate that Be, Cr, Ni, and Mn are strongly associated with the organic portion. Also differences among coal are significant as is indicated by the elements of Cd, Pb, Zn and Hg.

Enrichment ratio is defined as the ratio of an element's concentration in a given ash fraction to its ash equivalent concentration in the coal. Data presented in Table 2 indicate that the following elements are enriched in all fly ash fractions: As, Cu, F. Ni and Se.

Those elements enriched increasingly in the small fractions include Be and Hg. Only Ti and Mg of the 15 elements studied did not show enrichment. It has been illustrated that the enrichment ratio is inversely proportional to mean particle size. Only two elements (As and Se) were more enriched in the flue gas existing from the hot side plant than the cold side plant coal. The amount of trace element in the vapor phase as collected by the WEP may also provide additional explanation. These preliminary data tend to indicate that in general there exists more of the trace element in the vapor phase for the gas exiting the hot side plant vs the cold side plant.

Trace element emissions data may be used along with representative coal analyses to determine similar splits for other power plants. Similar data is available for potential trace element emissions from coal gasification facilities.

Two additional concepts were surfaced during these programs. (1) the conversion of sulfur in the coal into sulfur dioxide out the stack and (2) a comparison of Illinois coal vs. Western coal on a trace element pounds per BTU basis. It was shown that the combustion of a Wyoming coal resulted in a conversion of sulfur to SO_2 of 87.3 and 87.8 during two separate tests. Conversion of sulfur to SO_2 of a North Dakota lignite resulted in 98.1 percent conversion.

A comparison of Western Coal vs. Eastern Coal on a pounds per BTU basis concentration in the coal for some 27 elements showed that for two of those 27 elements Eastern coal had lesser concentration than Western coal; for 10 of the trace elements Western coal was less than Eastern coal and for the remaining 15 elements Eastern coal was about the same as Western coal. The elements for which element Western coal has lower concentrations are S, Cl, Sb, Pb, Ni, Zn, Cd, Co, As, and Fe. Eastern coal is lower in concentration for Mg and Ti.

IV. DISCUSSION OF COAL MINING AIR QUALITY STUDIES

Air quality impacts may be expected as a result of surface mining activities in the form of coal dust and soil-like particulate matter. The magnitude of the ambient air quality impact will be dependent upon several factors including, 1) the size of the mining operation, 2) the amount of fugitive dust control, 3) meteorological conditions, and 4) the distance from the mine. The last factor is extremely important because a large portion of the fugitive dust emissions are large particles (i.e. greater than 10 microns) which settle out fairly rapidly. This concept as a function of downwind distance and atmospheric disperion potential has been illustrated. It is seen that for a normal atmospheric stability (D") about 75 percent of the initial emissions settle out within the first 5 kilometers of the mine emission point.

A field research program was conducted at 5 surface coal mines in the Western United States in 1977. The primary objective of the program was to quantify the amount and particle size nature of particulate emissions from individual mining activities. Applying typical emission factors to a typical 1 million ton per year mine in the Western United States it was calculated that the emission rate will be about 3000 ton per year of particulate matter. It should be noted that about 800 percent of these emissions result from haul roads. It was observed through this research program that if a very general estimate of the amount of emissions is necessary and limited information on the mine is available a figure of 1.2 pounds of particulate per ton of coal mined may be used.

Control practices to minimize fugitive dust are available and to a certain extent practiced at Western U.S. coal mines. Best available control technology is required at all new coal mines.

SUMMARY

Continued research in the areas of quantification of mining emissions and the effectiveness of control measures is necessary. Continued investigations regarding the mechanism of trace element volatilization and effectiveness of control practices during coal conversion will refine our knowledge and ability to estimate trace element air quality impacts.

Figure 1

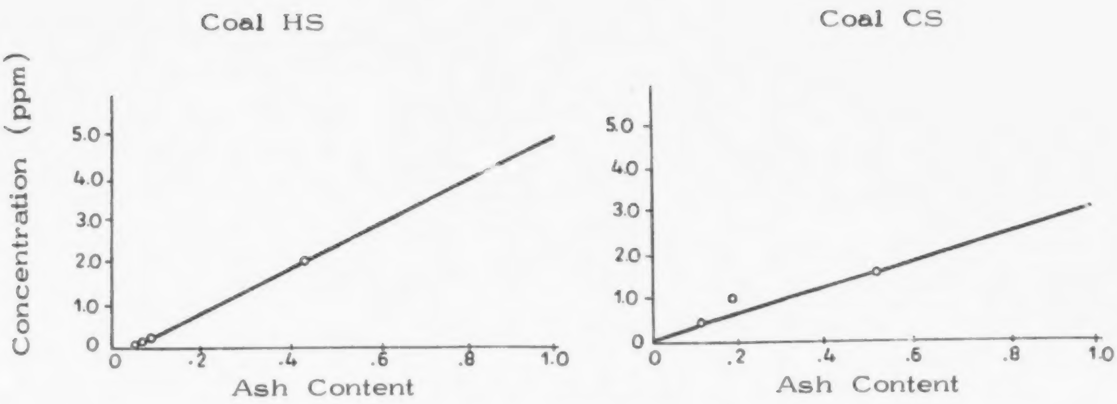

Figure 4-2. Arsenic Concentration vs Ash Content

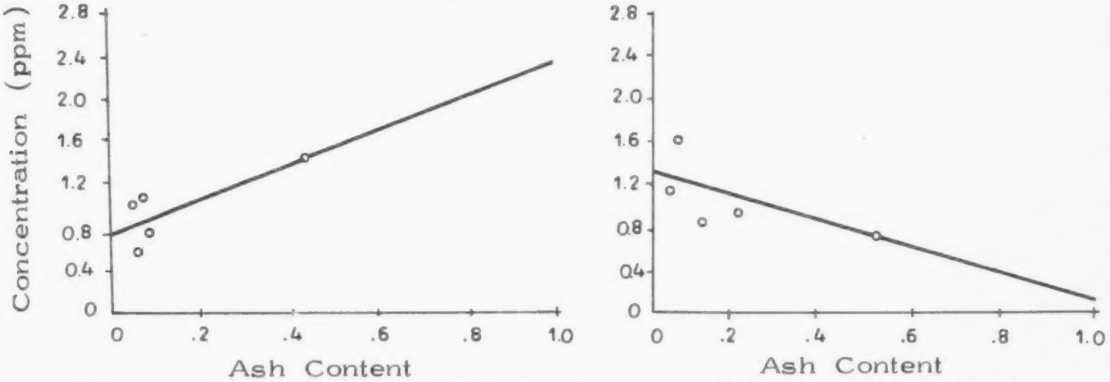

Figure 4-3. Beryllium Concentration vs Ash Content

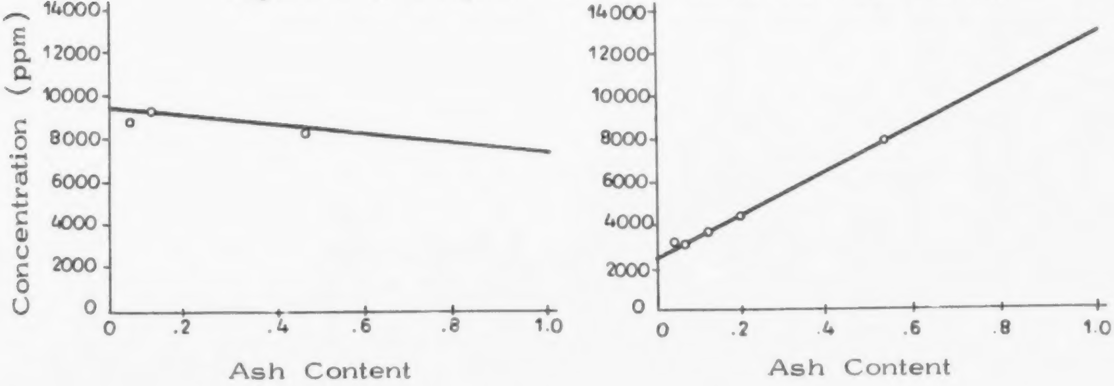

Figure 4-4. Calcium Concentration vs Ash Content

TABLE 1. ANALYSIS OF COAL SINK-FLOAT FRACTIONS[x]

Coal fraction	% of Raw Coal	% Ash	An	Be	Ca	Cd	Cr	Cu	F	Hg	Hn	Ni	Pb	Se	Ti	U	Zn
Coal HS																	
Float at 1.35	1.6	5.8	1.5	1.00	8890	0.50	9.5	12	61	0.24	23	7.3	3.0	0.70	520	1.0	7.0
Float at 1.45	98.4	6.8	1.1	0.53	9200	0.47	19	12	60	0.12	24	5.0	4.1	1.1	620	0.88	5.8
Raw Coal	100	7.7	1.2	1.05	9390	0.90	14	14	52	0.14	24	7.0	6.7	1.2	670	0.90	11.7
Sink at 1.35	98.4	7.9	2.3	0.75	9240	1.4	11	17	67	0.14	23	5.9	5.4	1.4	660	0.83	7.5
Sink at 1.45	1.6	43.4	20	1.4	8460	8.6	31	70	190	2.0	41	18	43	6.1	2640	2.3	89
Coal CS																	
Float at 1.35	41.5	3.9	0.85	1.15	3100	0.55	16	6.3	25	0.11	27	4.4	5.9	1.6	450	1.4	4.0
Float at 1.45	86.5	5.6	1.2	1.60	3180	0.45	10	10	32	0.09	32	2.8	5.6	1.6	800	1.2	6.5
Raw Coal	100	11.4	3.9	0.05	3730	0.70	13	14	54	0.11	34	5.1	11.7	1.8	990	2.0	6.5
Sink at 1.35	50.5	10.4	9.3	0.95	4140	0.70	21	25	54	0.19	37	3.9	12.1	1.0	1110	1.5	0.9
Sink at 1.45	13.5	51.5	15.0	0.75	7975	1.2	14	43	92	0.40	50	5.1	16.0	4.5	2000	2.2	15.6

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x All concentrations calculated on a dry weight basic and reported as ppm (Hg/g) unless otherwise noted. All values represent the average of duplicate determinations.

TABLE 2. ELEMENTAL ENRICHMENT RATIOS OF ANDERSEN COLLECTED FLY ASH FRACTIONS

Fly Ash Size Fraction	Concentrations as ug/g									Ash Fraction Distribution (%)
	An	Cd	Cr	Ca	Hg	Ni	Pb	Se	Zn	
Station HS:							[*]			
8.0	4.1	0.6	0.7	1.4	0.8	1.2	0.6	7.0	0.9	9.5
5.0 - 8.0	4.4	0.5	0.6	1.8	0.7	1.4	0.5	7.2	0.9	11.4
3.3 - 5.0	4.5	0.6	0.6	1.5	0.8	1.3	0.6	9.4	0.8	16.6
2.3 - 3.3	4.6	0.8	0.6	1.7	0.9	1.0	0.7	11.0	1.1	11.6
1.5 - 2.3	4.8	0.7	0.5	2.0	1.1	1.2	0.9	11.0	1.2	20.9
0.74-1.5	4.6	0.4	0.5	2.4	1.1	1.4	0.5	16.3	1.6	17.2
0.45-0.74	4.7	0.5	0.5	2.6	1.0	1.8	1.0	19.5	1.8	8.6
0.30-0.45	5.6	1.1	0.6	2.7	0.8	1.4	1.0	27	2.1	2.7
< 0.30 + Vaporons	44.6	4.4	2.8	9.7	7.8	3.2	—	563	30	1.6
E^{xx}	5.2	0.7	0.6	2.1	1.0	1.3	—	21	1.7	100
Station CS:										
> 8.2	1.0	0.7	2.0	2.7	2.1	3.4	1.4	3.7	6.4	15.3
5.1-8.2	1.7	0.5	1.8	2.6	2.0	2.9	1.4	2.8	4.6	6.8
3.4-5.1	1.8	0.6	1.8	2.9	2.2	2.8	1.4	2.6	4.3	10.1
2.4-3.4	2.6	0.8	1.9	3.2	2.3	2.9	1.7	2.7	3.9	10.4
1.5-2.4	2.2	0.7	1.7	3.5	2.9	2.9	1.9	2.6	4.8	16.6
8.77-1.5	2.2	0.9	1.8	4.0	3.2	3.3	2.0	2.0	5.5	21.8
0.47-0.77	2.6	1.0	1.8	4.8	3.6	3.3	2.1	2.0	10.5	13.2
0.32-0.47	4.1	0.9	3.0	4.9	3.4	6.4	2.0	5.3	23	2.5
0.32 + Vaporons	22	14.5	5.0	9.3	6.5	2.9	—	200	109	3.3
E^{xx}	2.8	1.2	1.9	3.7	2.9	3.2	—	9.2	9.7	100 %

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[*] Ratio of ash fraction concentration to ash equivalent concentration of coal

[xx] Mean enrichment of flue particulate fractions determined by combining the individual values in proportion to the ash distribution by Andersen collection.

AIR POLLUTION IN THE VICINITY OF LARGE THERMAL POWER PLANTS AND CONTROL

by

Ludwik Pinko[x/]

INTRODUCTION

The production of electric energy doubles every 7-10 years almost in all developped countries, Poland not excluded. Today, as well as in the next two decades - despite the large - scale program of developing nuclear power plants - the energy generated there will cover only a small percentage of the total power demand. Hence, recent emphasis is laid on the utilization of coal as a fuel for power plants. It follows that the amounts of the coal burnt continue to increase, and so do the emissions to the atmosphere. The magnitude of the emission is contributed by many factors, and especially by:

- the quality of fuel used
- the type of the burning systems, and
- the efficiency of the treatment installations employed.

As much as 95 % of the electric power and about 100 percent of heat in Poland is generated by coal-fired plants. In 1977 the domestic power industry has burnt 47.8 million tons of coal and 36 million tons of lignite. In this situation, the harmful emissions to the atmosphere produce many problems to be solved.

[x/] Ludwik Pinko, M.Sc. Director of Power Industry Environmental Laboratory "Energopomiar", Gliwice, Sowińskiego 3.

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The observations made so far, as well as the investigation results obtained show that it is not so much the fly ash which accounts for the increased pollution level, as some of the elements occurring in the fuel (such as sulfur, sulfur compounds and heavy metals) or some products generated in the burning process (e.g. nitric oxide). These are the toxic pollutants which create a serious hazard to the environment.

The most toxic substances contained in the process gases are sulfur dioxide and sulfur trioxide. Although a certain success has been achieved by reducing the dust emissions (for the least few years they have been kept on a level of 1.0-1.2 million tons yearly), the problem of gaseous pollutants (chiefly SO_2 or NO_x) is still far from being satisfactorily solved. The emissions of sulfur compounds from domestic power industry amounted to 1.2 million tons in 1972 and 1.8 million tons in 1977, which accounts for 50 % of the total for Poland.

In different countries there are held different views as to the significance of increased emissions to the atmosphere. Some experts in this domain conclude that immission, i.e. the concentration of pollutants in the near-ground-level air, is the factor which first of all affects the environment and leads to undesirable damage. It is therefore sufficient to increase the height of the smokestack, and in this way the concentration of the pollutants in the lower layers of the atmosphere will become lower this is a false idea. Despite this improvement, i.e. the construction of increasingly tall smokestacks, environmental damage continues to spread, and there is no evidence, that all of the pollutants released into the atmosphere will be precipitated in the form of fallout in the vicinity of the emission source. On the contrary, there is ample evidence, that the pollutants pass into higher atmospheric layers, where they are transported over a considerable distance. These conditions lead either to a widely dispersed fallout deposition of the pollutants over a much greater area or to their accumulation in the atmosphere, which results in the decrease of the solar radiation.

The results obtained from air pollution monitoring in a number of countries show that air pollution over large industrial and municipal agglomerations should be considered in an approach different from the one practiced for agricultural regions with no industrial pollution or single emission sources.

The measurement results for Warsaw (Poland), Ostrava-Havirov (Czechoslovakia), Dayton and Cleveland (U.S.A.) indicate that the contribution of power industry to SO_2 pollution in these regions amounts to 65-75 %, and the contribution to SO_2 concentrations in the near-ground air makes from 10 to 30 % only. This is due to the construction of tall smokestacks and to the application of technological processes effecting a wide-spread dispersion of pollutants.

In Polish power industry air pollution monitoring has already been carried out for many years. Nowadays every power plant being erected is at the same time equiped with a monitoring system. Such systems are operated for the following power plants: "Turów", "Kozienice", "Dolna Odra", Gdańsk, Power System, "Opole", "Bełchatów", and Warsaw Agglomeration Power System.

CHARACTERIZATION OF THE POWER PLANTS

"Turów" Power Plant and Turów region

This is the largest Polish power plant with an installed power rating of 2000 MW, located in south-west Poland, in an agricultural region, near the border with the German Democratic Republic. In the immediate vicinity, on the German side of the border, two power plants and a few industrial plants are operated.

The "Turów" power plant fires yearly 19 million tons of lignite with a calorific value of about 1600-1800 kcal/kg, and a sulfur content of about 0.5-0.6 %. The 4 smokestacks are 150 m high. One of the German power plants operates with two chimneys, 98 m high, and fires yearly 3 million tons of lignite of the same parameters as that fired by the "Turów" power plant.

The other German power plant fires yearly about 6 million tons of lignite with a calorific value of 1800 kcal/kg and a 0.6 % sulphur content, and has five smoke stacks each 100 m high.

The industrial plants located in the frontier zone in the German Democratic Republic burn a yearly total of 2 million tons of lignite. The height of the smokestacks varies from 60 to 90 m.

"Kozienice" Power Plant

The power plant is situated in a typical agricultural plainland. The recently installed power rating is 1600 MW (with further 1000 MW capacity in construction). The two smokestacks are 200 m high. The power plant is fired with bituminous coal of a calorific value of 4800 kcal/kg, and a sulfur content of about 1 %. The fuel used amounts to about 5 million tons per year. The immediate vicinity of the power plant is covered with forests. Two industrial plants: are located 19 km south and 40 km south west of the power plant, respectively.

Heat and power generating plants of Warsaw

The heat demand in the City of Warsaw is being covered from several sources, as shown in the Table below:

Table 1

No.	Heat source	Heat rating Gcal/h	Percent
1	Heat and Power Generating Plants of Warsaw	3,368	60.5
2	Municipal District Heating Plants	617	10.9
3	Individual boiler rooms	995	17.6
4	Tiled stoves and individual heaters	620	11.0
	Total	5,600	100.0

The Central Heating System of the City of Warsaw includes four heat generating plants.

The Żerań Heat and Power Generating Plant with an available heat rating of 1235.0 Gcal/h, is situated on the right-bank side of the Vistula River in the northern part of the city. The plant is fired with bituminous coal (with a 1.15 % sulfur content) in a quantity of 1.3 million tons/year. The two smokestacks are 100 and 200 m high.

The Siekierki Heat and Power Plant with an available heat rating of 1.216 Gcal/h is situated in the left-bank side of the Vistula River in the southern part of the City, has two smokestacks, 120 m and 200 m high, and fires bituminous coal with a sulfur content of 1.15 % in a yearly amount of 1.0 million tons.

The Powiśle Heat and Power Plant is located on the left-bank side of the Vistula River, has an available heat rating of 230 Gcal/h. The two chimneys are 30 m and 36 m high. The plant is fired with bituminous coal with a sulfur content of 0.75 % in a yearly quantity of about 250,000 tons.

The Wola Heating Plant is situated in the western periphery of the City. Its available heat rating is 2400 Gcal/h. The plant operates only during heating seasons, and is fired with mazout.

The Capital City of Warsaw is located at the Vistula River in the Central Plain in moderate climate and is characterized by a micro climate typical of large cities. The principal features of this local climate are raised temperatures, low humidity, increased volumes of overcast and precipitation, and decreased wind velocity within the boundaries of the municipal development as compared to open areas.

MEASUREMENT RESULTS

"Turów" Power Plant

Dust fallout deposition measurements

The monitoring system consists of 24 sampling sites. Maximum dust fallout depositions are recorded in the vicinity of the first German power plant. The yearly average dust fallout deposition in the area of the "Turów" Power Plant in 1977 varied from 90 t/km^2, 12 km from the Plant, to 670 t/km^2 at a distance of 1.2 km from the Plant.
At a distance of 2.5 km the recorded dust fallout deposition equalled 215 t/km^2. At a distance of 0.4-7.2 km from the Plant the yearly average dust fallout depositions exceed the admissible Standard Level (250 t/km^2/year).

SO_2 concentrations

SO_2 concentrations were measured by coulometry. It follows that the average SO_2 concentrations measured in 20-min tests varied from 0.0 to 1.50 mg SO_2/Nm^3. Daily averages ranged from 0.0 to 0.48 mgSO_2/Nm^3. These concentrations were recorded 2.9 - 13.2 km from the emission source. The admissible Standard Values for 20-min tests were rarely exceeded (0.5 %), and the admissible Standard Level for daily testing was exceeded more frequently (3.3 %), as compared to the permissible values of 0.9 and 5 %, respectively.

90 % of the SO_2 concentrations measured in 20-min tests ranged from 0.0 to 0.10 mgSO_2/Nm^3.

The Standard values for both 20-min and daily average concentrations are more often exceeded in the direction of prevailing winds.

"Kozienice" Power Plant

Dust fallout deposition measurements

The measurements were carried out at 22 sampling sites located at a distance of 1.2 - 35 km from the Plant.

The yearly dust fallout deposition varies from 34 to 80 t/km^2 and accounts for 13 - 32 % of the permissible level for protected areas, which is 250 t/km^2/year.

The highest dust fallout depositions were recorded in the direction of the prevailing wind (E and ESE) at a distance of 10 km from the Plant. These values make up an increase of 30 percent in relation to the background.

SO_2 concentrations

SO_2 concentrations measured in 20-min tests varied from 0.0 to 0.50 mgSO_2/Nm^3 and occurred at a distance of 5 km from the Plant in the direction of prevailing winds. The highest concentrations were recorded in January.

In all sampling sites, 90 % of the SO_2 concentrations measured in 20-min tests fell in the range 0.0 - 0.05 mgSO_2/Nm^3.

Average daily concentrations measured during the full testing period ranged from 0.0 to 0.122 mgSO_2/Nm^3, and met 11.4 - 34.8 % of the permissible values (0.35 mgSO_2/Nm^3).

Heat and Power Generating Plants of Warsaw

Dust fallout deposition measurements

On the northern fringe of the City, district Żoliborz, in the vicinity of the Warsaw Metallurgical Works, the fallout deposition approached 220 t/km^2/year. In the district Praga-North with many other industrial pollution sources the dust fallout deposition exceeds somotimes 300 t/km^2/year. In the central down-town an enormous temporary increase in dust fallout was observed in 1973 through 1975 within the area of the building site of the new Central Rail Station. The nearly dust fallout was as high as 900 t/km^2, and after completion of this construction in 1975 decreased down to 200 t/km^2.

In the vicinity of the Siekierski Heat and Power Generating Plant the dust fallout reaches somotimes about 300 t/km^2/year. This area is less inhabited so that the distribution of the dust fallout is similar to the one observed in an open area.

SO_2 concentrations

SO_2 concentrations were measured in 1973 through 1975 at 16 sampling sites. The average daily SO_2 concentrations in the atmosphere during the heating season varied from 0.06 to 0.30 mg SO_2/Nm^3 and met the Standards.

INTERPRETATION OF MEASUREMENT RESULTS

In the nearby vicinity of the power plant Turów the concentrations of pollutants are relatively high, but do not exceed the admissible level established by Polish Standards. In the power plant Kozienice the situation is evidently better. Both the dust fallout and the SO_2 concentrations are below the admissible level. They are also lower than the concentrations calculated in the foredesign.

The same pollutants emitted by the Warsaw agglomeration behave in a different manner. The complex of a large city is characterized by a specific climate preferring intensive thermal turbulence, which contributes to a better dispersion of the pollutants as compared to their dispersion outside the city boundaries. However, the present state of the art does not permit a quantitative assessment of the "isle and of heat" effect. An analysis of the maps of the dust fallout distribution in the area of the city of Warsaw shows that the influence of heat and power plants on the dust content in the atmosphere is of a local character only. The emissions from these plants are not responsible for the occurrence of the maximums observed, which markedly exceed those established by Polish Standards. The calculations and measurements of average SO_2 concentrations during heating periods show that the contribution of the heat and power plants to the overall SO_2 concentration level generated by all emission sources of the Warsaw agglomeration is as low as 10 %.

The development of the existing heat supply system, as well as the design of new heat and power plants operating with high stacks, will considerably decrease the air pollution over the city of Warsaw. This improvement will first of all consist in the elimination of individual heating and of small industrial boiler rooms.

PREVENTION METHODS

Long-term development programs are being prepared, which are aimed at decreasing the environmental hazard. Each Department has prepared a program of its own. In these programs some modifications in the technology of heat and power generation are proposed so as to abate the atmospheric emission of pollution. These are either waste-free technologies or such that produce minimum wastes. The programs also include a wide application range of treatment systems for process gases.

The power industry itself is interested in preventing air pollution and develops

- extensive R+D activities with the aim to introduce to fluidized bed combustion, that will allow for a considerable abatement of both sulfur compounds and nitric oxides emissions (the latter will be decreased down to one third those emitted nowadays),
- in all newly constructed power plants modern electrofilters are being installed with an efficiency of at least 99.8 %; old power plants are modernized, so as to eliminate less efficient treatment systems at the latest in 1985,

- a comprehensive program of heat production is developed for large industrial and municipal agglomerations,
- where possible, special coal mills with pyrite separators are installed, which reduce the sulfur content in the power coal by some 50 %,
- a system is designed for the desulfurization of coal by a dry method, and will be set in operation in one of the Silesian power plants in the very near future; this is a pilot plant and should its operation be a success, similar desulfurization systems would be applied on a larger scale;
- an installation is constructed for the desulfurization of furnace gases by a wet limestone method; the first installation of that type is now being set in operation; if the efficiency of the system proves to be satisfactory, further desulfurization systems of that type will be built and installed where possible.

The simplest solution to decrease the environmental pollution generated by power plants applied now everywhere is the construction of tall smokestacks (250-270 m high).

On of the larger power plants (1200 MW) operates a system with special storage of coal of calorific value of 5500 kcal/kg and a sulfur content of 0.5 % to be mixed with worse coal when needed. Itis expected thaf the programs presented above should bring positive results in the early eighties.

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